Appreciating individual differences: exposure time requirements in virtual space

Appreciating Individual Differences: Exposure time requirements in Virtual Space

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ABSTRACT

Learning the spatial layout of an environment is essential in application domains including military and emergency personnel training. Training each and every member of staff, however, within a real-world space cannot practically be achieved, especially if the space is under-development or potentially unsafe. This aim of this chapter is to contribute towards a better understanding of how individual difference factors impact upon the exposure time requirements needed to acquire spatial knowledge from a virtual environment. Although multimodal, the impact of this research is of direct relevance to mulsemedia technologies, since it shows how individual differences impact information assimilation; showing that user information assimilation, and therefore feedback, must be personalised for individual needs. The chapter looks at the importance of: gender, orientation skill, cognitive style, system knowledge, and environmental knowledge – showing how individual user differences significantly influence the training time required to ensure effective virtual environment spatial knowledge acquisition (SKA). We introduce the problem of contradicting literature in the area of SKA, and discuss how the amount of exposure time given to a person during VE training is responsible for the feasibility of SKA.

1. INTRODUCTION

LEARNING VIRTUAL SPACE

The ability to 'learn' the environment before engaging in navigation is an area of interest for a variety of application domains (Egsegian et al., 1993, Foreman et al, 2003). Traditionally spatial training is accomplished by providing users with maps and briefings of an environment. These methods, however, only provide topological knowledge of the environment, which whilst being more flexible, pays little attention to the details of routes and landmarks (Thorndyke, 1980; Golledge, 1991). Procedural learning has a distinct advantage as can be seen in an experiments of Thorndyke and Hayes-Roth (1982); where participants with procedural knowledge of an environment estimated route distances significantly better than participants who had acquired just topological knowledge. Navigation seems to rely heavily on previously acquired visual information, e.g. the process of re-orientation during navigation in a previously visited environments (Montello, 2005), which relies on previously seen "visual references" in order to adjust bearings during navigation. Maps and other traditional navigational equipment cannot provide this level of supporting information. VE training promises to provide procedural knowledge through exploration, and has caught the attention of a variety of researchers all attempting to discuss whether virtual training is more efficient than training through more traditional methods (Witmer et al., 1995; Goerger et al., 1998; Waller et al., 1998; Foreman et al., 2003).

Learning in virtual environments relies on the ability of users to develop an understanding of space by creating a cognitive map of the environment (Asthmeir et al., 1993; Cobb and d'Cruz, 1994; Silverman and Spiker, 1997; Clark and Wong, 2000; Riva and Gamberini, 2000). Cognitive maps are mental representations of space that people develop in order to acquire an understanding of space, both virtual and real, through either procedural knowledge or survey knowledge (Thorndyke, 1980; Golledge, 1991; Witmer et al., 1995; Goerger et al., 1998). When learning in a procedural manner, cognitive maps are created through the act of navigation (Montello, 2005). Navigation itself is made up of two separate and very distinct processes. The first of these processes is locomotion, which is the movement of a person within an environment. The second process is way-finding, which is the planning of routes that a person undergoes when trying to get to a specific destination (Montello, 2005). It is understood that during self-directed locomotion (where the person is actively moving about in the environment solving problems - such as avoiding obstacles), there is a tendency to acquire more spatial knowledge (Feldman and Acredolo, 1979). Virtual environment training provides self-directed locomotion without the possibility of a dangerous life-threatening situation, making it very suitable for emergency and military training.

Interestingly, research concerning spatial knowledge acquisition through VEs, provides a variety of contradicting results. The findings, although conflicting, appear to be subject to a key influencing factor, 'required exposure time' (Witmer et al., 1996; Darken and Banker, 1998; Waller et al., 1998; Goerger et al., 1998; and Darken and Peterson, 2001). This factor is the exposure time that a user will spend learning the environment in order to achieve spatial knowledge acquisition.

THE IMPACT OF TRAINING TIME

Witmer et al. (1996), Wilson et al. (1996), Waller et al. (1998), and Foreman et al. (2003) all conducted experiments in order to conclude whether spatial knowledge acquisition can be acquired from a VE representation of the real world. These experiments involved a group of participants navigating through virtual space and acquiring spatial knowledge, and then comparing the results to a group that learned the environment through conventional methods such as maps or photographs. These experiments concluded that a VE can be more beneficial than traditional training. However, this is only the case if a long exposure time is given to the users.

Darken and Banker (1998) reported that experts perform better using conventional methods such as maps, while Goerger et al. (1998) reported that all participants had a greater success using conventional methods. Goerger et al. (1998) acknowledge, that with longer exposure times, virtual reality training may in fact be more beneficial, however, this is hard to determine since the exposure times that a user spent in each experiment differed. Waller et al (1998) allowed for two minutes, Darken and Banker allowed for a set 60 minute exposure, and Goerger et al. (1998) allowed for a set 30 minute exposure, yet they referred to this as a short exposure time. It was, therefore unclear how much exposure time is deemed as required, and if in fact various environmental attributes and individual user differences can affect the required exposure time.

In an attempt to clarify this situation, Darken et al. (1999) and Koh et al. (1999) discussed why spatial knowledge acquisition research delivers contradictory results. They both made the argument that individual user differences are an extremely important factor in the development of cognitive maps, and that a one-size-fits all situation may not be possible when determining required exposure time. Darken et al. (1999) also examined how cognitive and biological differences affect a series of cognitive processes, which are critical to navigation. They stated that previous knowledge, aptitude, orientation ability, strategy, perceptual motoric and memorial knowledge, all influenced the navigational skill of the user. According to Koh et al. (1999) and Waller et al. (2001) there is a need to identify these individual differences and to understand how they affect performance when acquiring spatial knowledge. Therefore, we proceed by identifying and discussing commonly defined individual differences of users that affect navigation skills, and therefore the exposure time required to acquire spatial knowledge from a VE. Understanding how these individual differences affect navigational skill will help VE trainers understand the required exposure times necessary for a specific user to acquire spatial knowledge from a particular environment. Since people are different, a one-size fits all approach to training time does not seem logical.

INDIVIDUAL DIFFERENCES IMPACTING USER NAVIGATION

Individual differences have been considered for many years in Visuospatial research, which considers a very broad spectrum of research of understanding concerning images, space and spatial knowledge acquisition (Hegarty and Waller, 2005). This chapter considers the key individual user differences: gender, experience / knowledge, orientation skill, age, and cognitive styles. As suggested by Darken et al. (1999), each of these human attributes influence the navigational skills of the user when they navigate in a novel environment.

Gender issues in navigation

There is evidence that gender plays a significant role in acquiring spatial knowledge from a VE. Waller et al. (1998) showed that females were particularly disorientated in a virtual maze, since they reported large bearing errors when drawing a retrospective maze map. Although women's ability is more constrained when learning spatial characteristics of a virtual environment, their difficulty when navigating in the maze may be constrained by strategy rather than ability. Both Sandstrome et al. (1998) and Moffat et al. (1998) have provided explanations as to why male users navigate better in a maze. One of the deficiencies of a maze is that it relies heavily on geometrical navigation, rather than the use of landmark cues. Sandstrome et al. (1998) concluded that women rely heavily on the use of object landmarks for navigation, where men seem to use both structural landmarks and object landmarks.

The difficulty that women may face when navigating through an environment with limited landmarks, suggests that the required exposure time required by women to acquire the spatial information is increased when environments lack well placed object landmarks. Accordingly, women have problems navigating environments that are complex by nature (such as a maze), however this does not mean that for other types of environments their navigation skills will suffer, or that if given enough exposure time their knowledge of the environment will not equal that of the men. This theory is backed by Vila et al. (2002), who indicate that as exposure time in the environment increases, the navigational differences between the genders decreases.

Aptitude and Spatial Orientation Skills

The most discussed individual user difference, in the area of spatial knowledge acquisition, is orientation skill. Most experiments testing for spatial knowledge acquisition attempt to keep orientation skill consistent amongst participants (Witmer et al., 1996; Goerger et al., 1998; and Waller et al., 1998). It is obvious that research considers spatial orientation skills as being a very influential attribute during a variety of areas involving human-computer interaction, such as browsing and other visual tasks (Gomez et al., 1986; Vicente et al., 1987; Stanney and Salvendy, 1995). There is strong evidence that individuals have different orientation abilities, which are determined by biological factors (Smith and Millner, 1981; Maguire et al., 1996; Maguire et al., 1999; Maguire et al., 2000). Research points to the hippocampus area, which is placed in the centre of the brain, as being responsible for providing spatial memory. To measure spatial and spatial orientation, various spatial visualisation and orientation tests that can determine a person's orientation skill, such as the Guilford-Zimmerman orientation survey (Guilford and Zimmerman, 1948). Other tests exist (such as spatial memory, and spatial scanning tests), but spatial orientation tests are thought to be more successful in determining a user's ability to acquire spatial knowledge (Waller, 2001).

Although the orientation skill of a user is often thought to be the most critical individual difference, there is actually no proof, to the best of our knowledge, that it has the most impact on the required exposure time.

Cognitive Styles

The concept of people adopting different strategies in order to solve problems and make decisions was first presented by Allport (1937) who presented cognitive styles as a person's preferred way of perceiving, remembering, thinking and problem solving. Since then research has looked into cognitive styles, and has referred to them as persistent strategies adapted by individuals when faced with problem solving tasks (Robertson, 1985). In more detail, cognitive styles affect perceiving, remembering, organising, processing, thinking and problem solving (Liu and Ginther, 1999).

Many different learning strategies are consistently adopted by a user in order to solve a problem. Messick (1976) identified as many as 19 different cognitive styles, and Smith (1984) identified 17. Schmeck (1988) grouped them using two distinctly different, but general, learning styles. The first is a more holist learning style, which is referred to as field-dependent and seems to emerge from activity in the right hemisphere of the brain. The second is a more analytical learning style that is referred to as field-independent and seems to emerge from activity in the left hemisphere of the brain.

Field-dependent people are more passive when learning (Witkin et al.,1977), and prefer to learn information by focusing on the information as a whole - rather than breaking it down. Field-independent users are more active when learning new information and prefer to acquire information in a serial fashion by breaking it down (Pask, 1979). Goodenough (1976) and Witkin et al. (1977) stated that field-independent people sample more relevant cues to solve a problem, whilst field-dependent people sample more irrelevant cues to the current problem. In terms of landmarks, which are considered cues for navigation, field-independent users will benefit more from informative landmarks. This is also seen in research concerning 'hypermedia navigation' (Chen and Macredie, 2001), which indicates that field-dependent users were more efficient when they had to take a more holistic strategy, and navigate using a map of the overall system. In this research field-independent users benefited more from an analytical strategy, which included a depth-search of the entire system (Ford and Chen, 2001).

Knowledge and Experience of Environment and IT System

Knowledge concerning the system, whether it is a desktop computer that allows for mouse and keyboard input, or if it an immersive device, can have a limiting effect due to an overload of mental tasks. This overload is described by Booth et al. (2000) and is explained to be a limitation to attention due to unfamiliar controls and interfaces. According to Booth et al (2000) this occurs mainly because there is an attention dividing of tasks, which are required to navigate and perceive the information seen on the screen. More effort is required to understand and interact with the interface, therefore not enough attention is given to creating cognitive maps of the environment. In compensation, a longer exposure time is required.

More effort is also required if an environment is novel (i.e. if the user has never navigated through this type of architectural structure). In Human Computer Interaction, the difference during navigation between experts VS novices is critical for interface design (Dix et al., 1993; Eberts, 1994). Kuipers (1975), Brewer (2000) and Mania et al. (2005) explain how experience with a certain type of environment gives rise to certain structures in human knowledge memory. These structures are called schemas and are formed in human memory due to past experiences (Pelagatti et. al. 2009). Schemas consist of perceptual information and language comprehension, and are invoked when interacting with new information. The required exposure time to learn an environment depends on memory performance, which is in turn influenced by Schemas, which are affected by the consistency of items in the environment, i.e. whether an item is likely to exist in such an environment (Brewer and Nakamura, 1984). Another theory is called the inconsistency effect and argues that inconsistent items positively influence memory (Lampinen et al., 2001). It is clear that schemas are highly relevant to landmark information and that a person with strong past experiences navigating through a certain type of environment will be more able to recognise key landmarks, and therefore create a cognitive map faster than a similar person with no experience navigating within such an environment.

Knowledge of the environment was considered to be a variable in the experiment of Darken and Banker (1998), who only selected experienced mountaineers for their experiment. Darken and Banker (1998) reported, however, that the advanced mountaineers did not benefit from the 60 minute exposure time in the VE, yet did benefit from using a map. Interestingly, they did not, to the best of our knowledge, test user orientation skills. Instead, Darken and Banker (1998) used participants that have a large experience with navigating through real wilderness using cues and maps. This does not mean, however, that these participants were experienced with the VE system, or had a high aptitude and orientation skill.

2. EXPERIMENTION

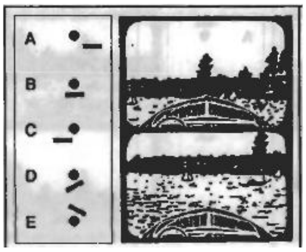
To control our experimental participants we: i) begin by selecting a large number of participants; ii) run pre-tests to control the impact as a result of confounding user individual differences; iii) placed participants into groups according to their individual differences; iv) developed a range of controlled virtual spaces for experimentation; v) had participants undertake controlled experiments. The following text aims to expand these stages.

OUTLINING EXPERIMENTAL PRETESTS

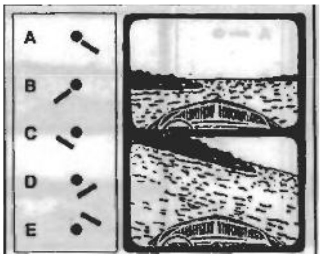
Since our research focuses on discovering the importance of five specific individual user differences (i.e. gender, orientation skill, cognitive style, system knowledge, and environmental knowledge), five difference filters were required. The following presents how participants were placed into appropriate participant groups by using pre-testing to minimise experimental variation between individual difference groups.

Gender - The most appropriate method of determining gender was through the use of a pre-test questionnaire, as used by Waller et al. (1998).

Orientation Skill - As with previous research in the domain of spatial knowledge acquisition, our work follows the standard test for determining participant orientation - the Guilford-Zimmerman orientation survey. This test comprises of various pictures of a boat along with multiple choice answers (see figure 1). Each picture is split into two. The boat in the lower image is at a different position and / or angle from the top image. The users must imagine the direction in which the boat moved. Direction and angle are represented by a series of dots and dashes, as seen in figure 1 (Guilford, Zimmerman,1948). The user must determine and select an answer. After scoring, participant are segmented into those with a relative high and low aptitude.



a) The boat has moved left and down, so the correct answer is C



b) The boat has moved to the left and downwards, and has rotated anticlockwise, therefore B is the correct answer

Figure 1 a/b – Questions in the GZ test

Cognitive Style - Many identified strategies are adopted by users in order to solve problems. Messick (1976) identified as many as 19 different approaches, yet Schmeck (1988) grouped them to form two distinct styles. The first is a more holist learning style, referred to as field-dependent and seems to emerge from activity in the right hemisphere of the brain. The second referred to as field-independent, is a more analytical style and seems to emerge from activity in the left hemisphere of the brain. This seems to relate to the learning styles of holistic strategy versus the serialistic strategy as proposed by Messick (1994). Field-dependent people are more passive when learning information, they prefer to learn information by focusing on the information as a whole, rather than breaking it down. Field-independent users are more active when learning new information and prefer to acquire information in a serial fashion by breaking it down. The implication that this has on navigation can be seen in previous research on 'hypermedia navigation'.

Chen et al. (2005) compared a variety of tools to determine the cognitive styles of their participants. They found that the best test was the Cognitive Styles Analysis (CSA) by Riding (1991). An alternative test that was considered, named the Group Embedded Figures Test proposed by Witkin et al. (1971), has several problems since levels of field dependence are inferred from poor field independence performance (Ford & Chen, 2001).

System Knowledge - Participant system knowledge was controlled through the use of both a questionnaire, and a mouse dexterity test. The questionnaire asked participants to declare how much they used a computer. A simple dexterity test was developed to measure the time it took a participant to click a box that appeared in a random corner of the screen. Twenty clicks were measured in total, and the total time was calculated. Participants that declared low system knowledge in the questionnaire took twice the time to click on the boxes as participants that stated that they were experts in using a computer.

Environmental Knowledge - Environmental knowledge is the only individual user difference being considered that can be experimentally altered. Environmental knowledge implies that a participant has experience navigating in a particular environment type; therefore by allowing a group of participants some "training" time before the experimental process begins, an increase environmental knowledge can be established. We selected a group of participants who were identical in nature to the control, and allowed them to navigate for five minutes in each of the environment types, in advance of the experiment, to give an increased environmental knowledge. A similar technique was used for the VR long-immersive group Waller et al. (1998).

The pre-tests were used to filter 100 original participants down to just 48 people. Six group were used, each consisting of 8 people with characteristics as defined in table 1.

Table 1 – Participant Groups

	Gender		Cognitive		Orientation		Environmental Knowledge		System Knowledge	
	M	**F**	**A**	**H**	**L**	**H**	**L**	**H**	**L**	**H**
Control	☑			☑		☑	☑			☑
Gender		☑		☑		☑	☑			☑
Cognitive Style	☑		☑			☑	☑			☑
Orientation Skill	☑			☑	☑		☑			☑
Environmental Knowledge	☑			☑		☑		☑		☑
System Knowledge	☑			☑		☑	☑		☑	

(M – Male; F – Female; A – Analytic; H – Holist; L – Low; H – High)

These six groups are: the control experimental group (male, holist participants with high system and orientation scores and low environmental knowledge – defined by the general nature of participants); the gender group (female participants – all other groups contained only male participants); the cognitive group (analytical – all other groups contained holist participants); those with low systems knowledge – all others were tested as having high system knowledge; those with high environmental knowledge – all others were not given the additional time within each environment; and those with low orientation skills – all others were tested as relatively high using the Gilford Zimmerman test.

DEVELOPING APPROPRIATE VIRTUAL ENVIRONMENTS

A desktop based maze environment, similar to the one developed by Waller et al. (1998) was created and used in our experiments. The environment was non-immersive and simply multimodal to minimise complexity, and therefore reduce the change of confounding experimental variables. The reason for using a maze environment was again to simplify perceptual input, since it has been theorized that people remember most angles as a right angles during the development of cognitive maps (Gillner and Mallot 1998). In order to investigate the impact of individual differences across a range of environments, four controlled environments were developed to consider significant variation of specific environmental factors.. Table 2 displays information about the environments that were developed.

Table 2 – Table of environments incorporated in the experimental process

Environment Type	Informative Object Landmarks	Size	Complexity
Control	High	Small	Low
Large Size	High	Large	Low
Complex Layout	High	Small	High
Low landmark	Low	Small	Low

The following text shows how environmental factors were implemented in our experiment:

Size - no formal definition exists as to what a large scaled environment is; as opposed to a small scaled one. Accordingly, we had to distinguish between a large and a small size environment. We reasoned that a space of approximately 75m x 75m should be used to represent the 'small' size category, as this can contain a single building floor-plan. A larger size 150m x 150m should represent the 'larger' size category, which could (if required) contain multiple locations.

Spatial Layout Complexity (SLC) - SLC relates to the number of objects, such as walls that obstruct the sight of a user from various reference points such as visible landmarks. A common and simple way used in literature of altering the complexity seems to be the use of walls to obstruct the user's vision in a virtual maze (Marsh and Smith 2001). This work used this approach as it allows fast VE development and consistent experimentation (see figure 2a).

Landmark information - Stankiewicz and Kalia (2004) present how landmark information is comprised of visibility and consistency, as well as how descriptive it is to the user. Altering these values renders a landmark more or less useable and can have a negative impact on learning - especially if the landmark moves to another location. There is some uncertainty as to what can be considered as a landmark, however Stankiewicz and Kalia (2004) argue that there are in fact two types of landmarks; structural and object. Structural landmarks are things such as T-Junctions, dead ends and other informative structures. Object landmarks are objects such as trees and paintings that do not determine the environmental geometry but are instead simple objects that can be used as navigational aides. The way of ensuring that useable landmarks are present in the environment is presented by Vinson (1999), who provides information on how to add landmarks and make navigation less complex. Therefore the landmark information was controlled by the amount of unique object landmarks available during navigation. All virtual environments were populated with a variety of landmarks that serve as an navigational aids for the testing phase. In our work, a low landmark count is defined as 4 unique landmarks in the whole map, a large count is that of 16 unique landmarks (see figure 2b).

a) 

b) 

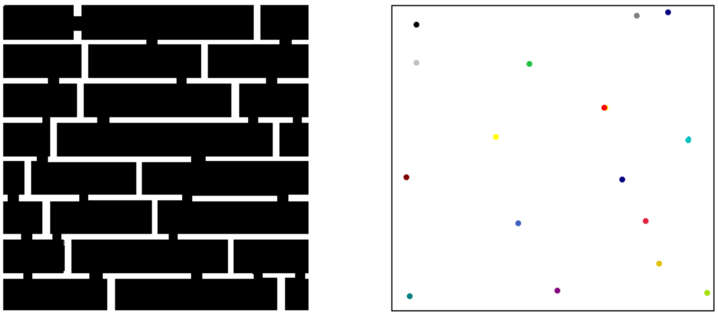
Figure 2: a) and b) shows view in the VE respectively before and after object placement

EXPERIMENTAL PROCESS

Once all participants were categorised, and environments were defined and created, experiments started. Four identical personal desktop computers were used; each set-up with one of the defined environments (as described in table 2). Participants in each group were separated into four subgroups with two participants from each group, and each subgroup was assigned a different experimental order, which was implemented to avoid a experimental order effects. Each participant was asked to move around the virtual space. Once each participant felt that they had ‘learned’ the layout of the environment, a paper map was handed to the participant. To judge whether the participant had ‘learned’ the space’ we used a method similar to the one justified in the experiments undertaken by Waller et al. (1998). In order to demonstrate that spatial knowledge was acquired, the participants had to point to the location of landmarks on the paper map. If the participant pointed to a space within the quad sector of the correct corridor, they were said to have demonstrated that they had 'learned' the position of the landmark. If they failed, the participant resumed navigation. A log was kept of participant actions, including the amount of time they stopped, as well as their total time.

Each group navigated in all four environments:

- Control environment (see figure 3) – all other environments differ from the control in just one way. The control environment is small, has two obstructions per row, and is populated with 16 unique object landmarks.
- The large environment is four times the size of the control environment.
- The complex environment has four, instead of two, obstructions (walls) per row.
- The low landmark environments has four instead of sixteen unique landmarks.



a) b)

Figure 3: Control environment: a) two obstructions per horizontal row (with 8 rows) b) 16 unique landmarks

3. RESULTS

In this section we look at the results from the six experimental participant groups (as described in table 1).

Understanding the Control

The control group is the benchmark participant group, which enables the impact of factors to be determined. The results of the control group are summarised in table 3.

Table 3 – Results of the control group

	Large Size	Complex Environment	Low Landmark Environment	Control Environment
Time Taken (mins) to acquire spatial knowledge from the environment	0:22:14	0:15:06	0:14:24	0:11:52

The results of the control group show the relative impact of different environments on the required exposure time. We ran separate univariate analysis of variance with respectively size, complexity and low-landmark as the independent variable and time as the dependant variable. All the environmental factors significantly impact exposure time (size - $F(1,1) = 395.913$, $P<0.01$; complexity - $F(1,1) = 18.717$, $P<0.01$}; and low landmark - $F(1,1) = 19.093$, $P<0.01$). Accordingly, it is critically justified that environmental factors must be considered to ensure correct exposure time.

Significance of Gender

Both Bryden and Tapley (1977) and Petersen and Linn (1985) implied that females were less capable at orientation than males in a VE. Waller et al. (1998), found that females are particularly disorientated in a virtual maze, with large bearing errors, and have difficulties in drawing the maze that they just navigated through. Moffat et al (1998) reported that males learn a virtual maze faster than females, while Crook et al (1993) suggest that males learn a topographical map faster than females.

The gender group in our experiments had similar results in all pre-tests to the control group; so the only difference was in respect to gender (females). The results of the gender group can be seen in table 4. To compare between the gender group and the control group we used separate independent sample T-Test for each environment, allowing us to determine whether the gender significantly impacted required exposure time from different environments.

Table 4 – Results (H:M:S) and statistical significance of gender (gender vs control group)

	Large Size	Complex	Low Landmark	Control
Time taken by the gender group	0:23:19	0:16:04	0:20:31	0:13:05
Time taken by the control group	0:22:14	0:15:06	0:14:24	0:11:52

For the control, large size and complex environments there was no significance difference. For the low landmark environment, however, a considerable significance occured (Mean Difference 0:06:07; Std Err 0:00:37, $p < 0.001$). This implies that women take much longer in low landmark environments to acquire spatial knowledge than men. This finding supports the results of Sandstrome et al. (1998), who concluded that women rely heavily on the use of object landmarks for navigation; more than men who seem to use both geometrical and spatial structures and landmarks for navigation and development of cognitive maps.

Results indicate that gender only significantly impacts required exposure time in an environment with low frequency of unique landmarks. Interestingly, unlike the within relationship for the control group there was a significant difference between time taken to acquire information from the complex and low landmark environments. Our experiment therefore concludes that women performed just as well as men when it comes to acquiring spatial knowledge in all types of environments, with the exception of environments with low landmark frequency. This finding raises a concern that women must be provided sufficient landmarks in a virtual environments or female navigation and acquisition of spatial information will be negatively impacted when compared to men with a similar user profile.

Significance of Cognitive Style

An important question, concerning cognitive styles, is whether field-independent users would have better scores in a landmark-rich environment than field-dependent users. We initially hypothesized that field-independent users would acquire spatial knowledge faster than field-dependent users, due to their tendency to learn faster in a less-procedural way (such as that of traditional maps). The cognitive-style group was identical to the control, except that participants had a analytical cognitive style. The time results of the cognitive style group can be seen in table 5. To compare between the cognitive group and the control group we used a separate independent sample T-Test for each environment. This allowed us to determine whether the cognitive style of the user (analytical / holistic), significantly impacted the time taken to acquire information from different environments.

Table 5 – Results (H:M:S) and statistical significance of cognitive styles

	Large Size	Complex	Low Landmark	Control
Time taken by the cognitive styles group	0:27:44	0:12:34	0:15:14	0:12:46
Time taken by the control group	0:22:14	0:15:06	0:14:24	0:11:52

No significant difference occurred in the control environment, however for the large size environment a significance did occur between analytical and holistic users, with holist users taking significantly less time than analytical (Mean Difference 0:05:19; Std Err 0:00:30, $p < 0.001$). For the complex environment, this test showed a significance difference between analytical and holistic users, with analytical users taking significantly less time to acquire information from the complex environment (Mean Difference 0:02:32; Std Err 0:00:47, $p = 0.006$). For the low landmark environment, no significant difference was measured, which implies that the number of landmarks does not significantly impact the results of people with different cognitive styles.

Holist users (the control group) seemingly require less time to learn the relative visual references, since they focus on information within the environment as a whole. When placed in a larger environment, holist users more quickly acquired spatial knowledge, when compared to analytic users; as learning the interaction of landmarks in the visual field took less time than the specific placement of disparate and distributed objects. Siegel and White (1975), states that people first learn landmarks, then learn routes, and only then create a cognitive map of the area. If analytic users take more initial time to analyze the difference between specific object landmarks, results imply that additional exposure time should be allocated to field independent individuals to allow them to develop an understanding of specific objects in large size environments.

For the complex environment, our test showed a significant difference between analytical and holistic users; with analytical users taking significantly less time to acquire information from the complex environment. As previously stated, field-dependent people are more passive when learning information, and therefore prefer to learn by focusing on information as a whole, rather than breaking it down (Pask 1979). Moreover, Goodenough (1976) and Witkin et al. (1977) state that field-independent (analytic) users sample more relevant cues, such as signs pointing in relative directions. Increasing the complexity of an environment reduces the number of objects in the current field of view, and therefore reduces the ability of the holist user to determine the relative visual relationships between landmarks. This increases the time required for field-independent users to learn an environment “as a whole”. A complex environment layout instead supports procedural learning of specific objects, and therefore aids analytic users; who “breakdown” information to facilitate the development of a cognitive map. It would be interesting to look at this issue further, to help provide a better understanding of how cognitive style limits specific users when undertaking virtual environment training (e.g. training military personnel).

Significance of Orientation Skill

Perhaps the most discussed individual difference relating to navigation is orientation skill (OS). The OS group in this research differed to the control group, as they had low scores in the Guilford Zimmerman orientation survey. To compare between the low orientation group and the control group (see table 6) we needed to do a separate independent sample T-Test for each environment. This allowed us to determine whether the orientation skill of the user significantly impacts the time taken to acquire information from different environments.

Table 6 – Results and statistical significance of orientation skills

	Large Size	Complex	Low Landmark	Control
Time Taken by the OS group	0:28:09	0:20:06	0:20:21	0:17:33
Time taken by the control group	0:22:14	0:15:06	0:14:24	0:11:52

Results showed a significant difference between those with high and low orientation skills, when navigating in all environment types. In fact, orientation skill appears to be the user individual difference that most impacts spatial knowledge acquisition. Someone with a low OS is therefore “doomed” to suffer with navigation. Individuals can enhance their OS score over significant durations through pro-longed training; however this process will take a very long time and would not be practically feasible when acquiring spatial knowledge from a VE.

Significance of Environmental Knowledge

Environmental knowledge relates to knowledge and experience that a participant has within a specific environment type. Research suggests that a user may find a novel environment more difficult to navigate. The time taken for the high environmental knowledge group can be seen in table 7. To compare between the high environmental knowledge group and the control group we did separate independent sample T-Test for each environment. This allows us to determine whether high environmental knowledge significantly impacts the time taken to acquire spatial information from different environments.

Table 7 – Results and statistical significance of environmental knowledge

	Large Size	Complex	Low Landmark	Control
Time taken by Environmental knowledge group	0:18:57	0:11:25	0:10:42	0:08:07
Time taken by the control group	0:22:14	0:15:06	0:14:24	0:11:52

Results showed a significant difference between those with high and low levels of environmental knowledge for all environments. It is interesting that even though the experience time was only short, users showed a significant decrease in the overall time taken to acquire spatial knowledge. The result suggests that navigators with experience in a certain type of environment have the competitive advantage over novices, and supports the notion that “experienced” navigators carry knowledge of navigating through a certain type of environment to various environments made up of similar factors.

Significance of System Knowledge

Level of system knowledge can have a significant effect on learning. Pass et al. (2003) stated that different interaction methods impose different cognitive loads onto the user. If a new or complex system is needed as part of a task, the users’ ability to complete the task may be constrained by not having enough available working memory (Cooper, 2004); since it is theorised that working memory is extremely limited in capacity and duration. As the complexity of cognitive elements increases, so does the amount of required working memory (Chandler and Sweller, 1996). Since a user with low system knowledge is also learning the system, whilst undertaking the task, this increases cognitive load. Accordingly, low system knowledge can result in mental overload via a process called 'attention divide' (Booth et al. 2000); where a user’s attention is split between learning how to use the computer and solving the task at hand. The ‘system knowledge’ group was made up of participants who had little or no knowledge of computers. These participants had the lowest scores on the mouse dexterity test, which was created to test a participants’ ability with the input devices. The time taken for the ‘system knowledge’ group to acquire spatial knowledge from the different environments is displayed clearly in table 8. To compare between the low system knowledge group and the control group we did separate independent samples T-Test for each environment. This allows us to determine whether a low level of system knowledge significantly impacts the time taken to acquire information from different environments.

Table 8 – Results and statistical significance of system knowledge

	Large Size	Complex	Low Landmark	Control
Time taken by the low system knowledge group	0:28:28	0:20:21	0:20:09	0:15:45
Time taken by the control group	0:22:14	0:15:06	0:14:24	0:11:52

Results showed that a significant difference between those with high and low level of system knowledge for all environments. Accordingly, we have shown that system knowledge, the most easily trainable skill, significantly impacts the required exposure time for all environments.

The results from the 'system knowledge' group strongly support the findings of Booth et al. (2000). Participants with low level of system knowledge required significantly longer exposure times in all environments, when compared to the control group. The implication of this result on navigation training is that people with less experience of a particular computer system or device interface style will have a significant disadvantage when learning the spatial layout of the VE; when compared to those people with previous experience of the system of interface. Accordingly, those with lower experience of the system and interface require more exposure time, or additional system training.

Summary

This section has presented results that show that certain individual differences impact the exposure time required to effectively acquire information from virtual space. In summary results show that:

- Gender: (i.e. women) require significantly more exposure time when navigating in a low landmark environment.
- Orientation skill: (i.e. those with low OS score) need significantly more exposure time in all types of environments.
- Cognitive style: If a user is analytic, exposure time is significantly negatively affected in large environments, yet significantly positively affected in complex environments. If a user is holistic, exposure time is significantly positively affected in large environments, yet significantly negatively affected in complex environments.
- Environmental Knowledge: (i.e. those with environment pre-knowledge) require less exposure time in all environments.
- System knowledge: (i.e. those with low system knowledge) require more exposure time in all environments.

4. CONCLUSION AND REVIEW OF IMPLICATIONS

Virtual mapping, modeling and use in training is of growing importance. It offers significant potential in the effective training of staff, especially in developing or unsafe space, however a one-size fits all approach cannot be justified. As virtual training receive increased acceptance, and as additional mulsemedia technologies increase the complexity of interacting information assimilation, it is critical that personalization of VR content is considered to minimize the impact of individual user differences.

This chapter has contributed towards a better understanding of how individual differences impact exposure time required to acquire spatial knowledge; and has yielded the following results:

- Overall, orientation skill is the most influential skill, in terms of the mean total time taken throughout the environments, yet this skill is difficult to train.
- System knowledge seems to be the second most important skill, and is fortunately easy to train, as it is a matter of getting accustomed to the training interface.
- Environmental knowledge is also important throughout, in all environments, experts will have an advantage over novices. Fortunately, research suggests that this skill can be trained over time.
- Females have a serious disadvantage when it comes to learning from environments that are low in the number of unique landmarks. Whether this can change after training, is something that could be looked at in future work. Theoretically, however, a female with high environmental knowledge, and high system knowledge, could out-perform a male with low environmental and system knowledge.
- Field-independent users will acquire spatial knowledge faster from a complex environment; however field-dependent users have the advantage in large environments. These learning styles are formed through life, and it is unlikely that a learning style will change through training.

Significant legal, political and ethical implications exist for any organizations or governments who do not supply appropriate training to staff that later leads to injury or death. As exposure of untrained staff is inappropriate, use of personalised mulsemedia training technologies offers considerable opportunities for removing training safety concerns. This chapter has shown clearly that user individual differences impact spatial knowledge acquisition. User individual differences also potentially impact factors including: perceived level of immersion, impacting level of presence; and multimodal information assimilation, which will impact the level of different information types being assimilated by users. Mulsemedia virtual space provides a significant opportunity for those who require additional periods of training, however personalized user requirements must be considered if effective information transfer, and effective immersion, is to be achieved.

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