UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL, HUMAN AND MATHEMATICAL SCIENCES

Exploring Orientation within Geovisualisations and

Virtual Nested Environments

By

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ABSTRACT

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Spatial orientation is the ability to maintain knowledge of our position with respect to other cues within an environment. This is an essential skill, forming the foundation of other abilities, including spatial navigation. Previous research has identified that virtual environments impede participants' ability to orient accurately. Research exploring the role of environment type, specifically nested environments, has further identified a situation which hinders orientation ability. This thesis seeks to link these research bodies, exploring orientation ability within virtual nested environments. Across a series of experiments, it was found that participants struggled to accurately orient within these environments, especially when a link to the external environment was unavailable. The addition of orienting cues within the environment, however, reduced this difficulty. Participants provided with additional cues recorded significantly lower orientation error. This effect is apparent following either active exploration or a passive video tour. Subsequent studies illustrated that other factors such as anxiety, as manipulated via the use of stereotype threat, also influenced orientation accuracy within a nested environment. Geovisualisations were explored to examine whether orientation difficulties are observed in symbolised, rather than realistic, virtual environments. Participants reported orientation difficulties and demonstrated an inability to accurately track their position within symbolised space. Results suggest that geovisualisation users, similar to users of virtual nested environments, require increased support to efficiently orient. Results support that orientation within digital nested environments is difficult due to the lack of consistent visual cues within the multiple aspects of the environment.

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DECLARATION OF AUTHORSHIP

I, Craig Allison declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Exploring Orientation within Geovisualisations and Virtual Nested Environments

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;

2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;

3. Where I have consulted the published work of others, this is always clearly attributed;

4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;

5. I have acknowledged all main sources of help;

6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

7. Sections of this work has formed the foundation of the following conference presentations:

Allison, C. K., Treves, R. W., & Redhead, E. S. (2013, April). The Usability of Online Data Maps: An Ongoing Web Based Questionnaire Investigation into Users' Understanding and Preference for Geo-Spatial Visualisations. Poster session presented at GISRUK, Liverpool, UK.

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Signed:...

Date:...

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Definitions and Abbreviations

GIS	Geographical Information Science
CS	Condition Stimulus
US	Unconditioned Stimulus
V	Associative Strength
α	Learning Rate Parameter
λ	Maximum Associative Strength

Chapter 1

Literature review

Introduction

Technical developments over the last decade have enabled a rapid growth in the availability of virtual spatial environments; including computer generated 3D environments and digital maps (Wasko, Teigland, Leidner & Jarvenpaa, 2011). Within popular culture, it is estimated that 97% of American adolescents spend more than an hour a day playing video games (Granic, Lobel, & Engels, 2014). When considering digital maps, Google Maps receives over 58,880,000 unique visits every month in the USA alone (Marks, 2012). There is little question then that digital spatial environments are an important part of daily life for many. Despite this popularity, questions remain over how users are engaging with these environments and what can be done to facilitate use. As these environments become increasingly available, their applications and uses grow.

Digital environments are becoming a staple within a range of educational practices (Slator et al., 1999; Redfern & Naughton, 2002), for example via the increasing use of collaborative online working environments and tools facilitating engagement for distance learning programmes. Digital environments are also used within rehabilitation programmes, for example using virtual environment training programmes to facilitate motor recovery for stroke patients (Subramanian et al., 2007). The key questions explored within this thesis are whether users of digital environments, both realistic digital environments and digital maps, can remain orientated and whether users' ability to orient can be facilitated to make using these environments easier.

Spatial orientation can be defined as the *"ability to perceive spatial patterns or to maintain orientation with respect to objects in space"* (Ekstrom, French, Harman & Dermen, 1976, *p*149). Maintaining spatial orientation can be seen as essential in understanding the layout of both our local environment and wider connected spaces. It has been argued that successful orientation is a prerequisite for navigation (Parush & Berman, 2004). The ability to orient, navigate and use spatial environments, including real world locations, computer simulated environments, or abstract representations of space, such as maps, is an increasingly essential skill. Proficiency to complete these tasks has however been shown to significantly vary between individuals (Waller, 2000). Due to the increasing importance of these skills, efforts to assist people who struggle utilising the environments currently available should be a priority.

Spatial cognition research has embraced digital environments (Loomis, Blascovich & Beall, 1999). The use of digital environments has allowed researchers to manipulate environments in ways which would not be possible within the real world. As the complexity of available virtual environments advances there is need to examine factors which influence participants' ability to orient within these environments. It is this field that this thesis seeks to expand. Due to their growing importance, both industry and government are keen to explore digital environments and geovisualisations (Keim, 2002). Potential interventions will be explored to examine whether orientation can be made easier.

Current Research Focus

This thesis explores the role of spatial orientation in a variety of different scenarios. The initial two empirical chapters will examine the role of orientation within geovisualisations, symbolic spatial environments. Following the completion of these studies which were largely exploratory, it became apparent however, that a more controlled approach to examining orientation within digital environments was required. The thesis will therefore shift focus to examining first person digital environments, specifically a digital nested environment, examining the environmental cues which participants are using in order to remain oriented. The final empirical chapter within this thesis will examine the role psychological manipulation, specifically stereotype threat, has on participants' ability to remain oriented within both a digital nested environment and a digital maze. Finally potential future research directions will be explored.

Defining Spatial Ability

Spatial orientation can be viewed as the ability to maintain knowledge of where we are with respect to other cues within an environment (Satalich, 1995). The ability to be able to identify our current location within any environment is fundamental to successfully understand the environment and navigate within it (Parush & Berman, 2004). Despite the essential nature of these skills, numerous researchers have questioned an individual's ability to successfully orient within digital, as opposed to real world, environments. Although the focus of research within this thesis is digital environments, it is important first to consider spatial cognition within the real world, how spatial ability develops and spatial knowledge acquired, before considering why this process may be impeded within digital environments.

The concept of spatial ability is not clearly defined. An early definition of spatial cognition was offered by Thurstone (1938) who suggested that spatial cognition is the ability to hold a mental image of an object and to manipulate that image to match alternative views of that object. Although this definition has become the foundation of many spatial tasks, for example the Vandenberg Kuse mental rotation test (1978), this definition is inadequate when considering active spatial tasks, such as orientation and wayfinding (Spence & Feng, 2010). Alternative definitions include those offered by Linn and Petersen, (1985, *p*1482) who suggest that spatial knowledge is the ability to *"represent, transform, generate and recall symbolic, non-linguistic information"*, whereas Bertoline (1998, *p*184) suggests that spatial cognition is a *"mental process used to perceive, store, recall, create, edit, and communicate spatial images"*. Gardener (1983) suggests that visual spatial ability is a distinct branch of intelligence, one of the seven types he suggests within his theory of multiple intelligences, defined as the *"ability to create and manipulate mental images, and the orientation of the body in space"*. Consistent between all definitions however is that spatial ability concerns an individual's ability to manipulate objects and visual scenes. Waller (2000) suggests that spatial ability is comprised of multiple related dimensions, including spatial visualisation, the ability to mentally manipulate objects and figures and spatial orientation, the ability to account for view point changes (McGee, 1979). Based on the definition of Waller (2000) the ability to remain oriented can be considered essential in an individual's ability to understand their environment and their location within it (Kelly, McNamara, Bodenheimer, Carr & Rieser, 2009).

The Acquisition of Spatial Knowledge

In order to be able to orient within an environment, individuals must possess a spatial reference system, allowing them to place objects within a spatial array (Shelton & McNamara, 2001). Clear proposals have been made regarding the nature of humans' representation of space, and how this representation develops. In particular, distinctions have been made between egocentric (self-centred) representations of the environment and allocentric representations (environment-centred) (Chen, 2014). Numerous theories have been proposed to account for how this knowledge develops. Arguably however, the most influential theory (Arnold et al., 2013) which has emerged for the acquisition of spatial knowledge remains the Landmark-Route-Survey model proposed by Siegel and White (1975). Siegel and White's (1975) developmental theory suggests that spatial knowledge can be divided into three qualitatively distinct stages, knowledge of landmarks, understanding routes that exist between distinct landmark pairings and finally knowledge of a survey, or map like, representation of the environment. With experience, individuals are able to learn about current and related environments, so that they understand a variety of alternative spatial environments, a process labelled as spatial cognitive microgenesis (Siegel & White, 1975). Knowledge of routes can be seen to account for egocentric understanding, whereby directions are with respect to the navigator and a landmark target, whereas survey knowledge, grounded in the gestalt configuration of the environment is allocentric understanding, the relative position of landmarks is independent of the navigators position. This theory will be explored here, before discussing criticisms which have been addressed towards the model.

The foundation of Siegel and White's (1975) theory is knowledge of landmarks. Landmarks are visually salient objects within a given environment which can be used to identify a specific point or location, for example a town hall within a village or an intersection between two roads. Landmark knowledge does not contain any relational understanding; the landmark can be encoded merely as a visual target. Landmarks can be seen as nodes within an individual's spatial array, a distinct collection of, initially unrelated targets. Each landmark has the potential to anchor an individual's location, providing orientation locations (Nash, Edwards, Thompson & Barfield, 2000). By learning how to navigate between two distinct landmarks, individuals can develop route knowledge.

Routes are connections between multiple landmark pairings (Siegel & White, 1975). Route knowledge is viewed as a series of ordered instructions, primarily pairing an action (or an instruction) with a given landmark, for example turn left at the church (Vinson, 1999). Route knowledge allows individuals to orient themselves on multiple paths to develop a detailed series of route memories allowing for effective navigation and reorientation at key locations (Argawala & Stolte, 2000). Despite being an effective navigation strategy, route information does not encourage the acquisition of new knowledge; a learnt route between different landmarks is reliable so that no further knowledge is required. Following a route however does not encourage exploration beyond the learnt route (Parush & Berman, 2001) even if more efficient paths are available. For example, if you know the route between your home and the university and your home and the shops, there would be no need to work out the route from the university to the shops, you only have to return home then go to the shops. Despite enabling effective navigation, route knowledge is restrictive when considering orientation decisions as direction estimates between unpaired landmarks is not possible.

Should an individual continue to explore their environment, they may further their understanding by developing survey knowledge. Survey knowledge is frequently considered to be "map like" (Montello, Waller, Hegarty, & Richardson, 2004), grounded in the gestalt configuration of the environment, not viewing landmarks and routes in isolation but rather as part of a larger space (Ruddle & Peruch, 2004). This includes understanding the spatial relationships between various landmarks based on abstract metrics, for example the library is 100 meters northwest of the town hall. As survey knowledge encompasses a representation of the wider environment, individuals using survey knowledge are more able to complete active navigation tasks, including finding novel routes and making spatial decisions (Thorndyke & Hayes-Roth, 1982). Survey knowledge also allows the navigator to complete spatial inference tasks (Thorndyke & Hayes-Roth, 1982), for example estimating distances and potential routes between two previously untraveled to locations (Kallai, Makany, Karadi & Jacobs, 2005). Consequently, survey knowledge allows the navigator to infer novel routes. This is in contrast to navigation via pre-set paths apparent during route based navigation (Kuipers, 1978). If the shops are closer to the university than home, having survey knowledge would allow you to go straight from the university to the shops rather than returning home first. It can be seen that all survey representations require abstraction, a process that could not occur within route understanding. Lawton (1994) argues that survey knowledge implies the construction of a cognitive map (Tolman, 1948), whereby elements within the environment are integrated into a mental representation.

Route and survey knowledge differ on several key elements. Whilst route knowledge is founded within an egocentric reference frame, based on an individual's current position within an environment, and is representative of locations within the navigators direct perception (Wilson, Wilson, Griffiths & Fox, 2007), survey knowledge is allocentric, based on environmental layout (Werner, Krieg-Bruckner, Mallot, Schweizer, & Freksa, 1997; Burgess, 2006). Allocentric reference frames can be viewed as originating from the features of the environment rather than the explorer's position (Wilson, Wilson, Griffiths & Fox, 2007). Mou, McNamara, Valiquette and Rump (2004) suggest that within an egocentric reference frame, understanding is driven by knowledge of the self to object spatial relationships. This can be contrasted with the understanding of object to object relationships present within an allocentric reference frame. Consequently, for route based knowledge, whether an individual turns left or right at a landmark is dependent on the direction of travel, the navigators' position is of central importance, with many individuals struggling to follow routes in reverse (Kuipers, 1978). In contrast, survey knowledge is route independent and supported by abstract metrics including cardinal direction (North, South, East or West) and distance, as such the navigator's position within the environment is of less importance. Whilst Siegel and White suggest that *"all spatial representations are functionally landmarks connected by routes" (p24),* survey knowledge as an allocentric representation is based on the gestalt configuration of the environment rather than a landmark action pairing seen within route knowledge. This difference is supported by perspective differences between route and survey knowledge, with route knowledge best described as first-person, compared to an ornithological view of survey knowledge (Montello et al., 2004). Although differences between route and survey knowledge are well established, research is mixed regarding how this knowledge develops.

To understand how an individual learns the location of different elements within an environment, it is worth considering how spatial knowledge develops, and whether landmark, route and survey knowledge are acquired independently or concurrently. Siegel and White (1975) argue that development of spatial knowledge is a linear process driven by sensorimotor experience, primarily via active exploration. As each learning stage, landmark, route and survey, are qualitatively distinct, an individual must develop sufficient understanding before progressing to the next stage. That is an individual cannot develop route level knowledge until they have established an understanding of the landmarks that exist within the environment. Siegel and White suggest that each stage of spatial knowledge is dominated by different sensory inputs. Landmark knowledge is driven by visual information, based on the identification of clear targets within the environment. Route knowledge is also supported by kinaesthetic feedback gained as the individual travelled between landmarks, and idiothetic information, knowledge of self-position, gained as the individual moves (Mittelstaedt & Mittelstaedt, 2001). As landmark knowledge and route knowledge are driven by different sensory inputs, survey knowledge develops once sufficient multisensory information has been experienced and the navigator has a complete understanding of landmarks and routes. Central to Siegel and White's theory is the linear development of qualitatively distinct spatial understanding, driven by sensory motor experience.

Although Siegel and White's (1975) theory has become the *"dominant framework"* (Montello, 1998, *p*143; Ishikawa & Montello, 2006), many researchers have questioned whether spatial knowledge is gained linearly as predicted by Siegel and White (1975) theory. Garling, Book and Ergezen (1982) found that within an unfamiliar town, students learnt the relative positions of landmarks (survey knowledge), before being able to plot routes between them (route knowledge). Similarly, Montello and Pick (1993) found that it was possible to develop survey knowledge as a result of very limited environmental exposure. Conversely, Stevens and Coupe (1978) found extensive differences between an individual's mental representation of an environment and the real environment even after extensive direct experience, suggesting that experience does not always lead to the generation of accurate survey knowledge. Based on these and similar findings, researchers such as Montello (1998) argue that the process of developing spatial knowledge is a series of refining steps, with landmark, route and survey knowledge developing simultaneously. More recent research has largely begun to explore the differences between route and survey knowledge in greater detail (Steck & Mallot, 2000; Castelli, Corazzini, & Geminiani, 2008), however, the core distinction between knowledge types has remained.

Building upon the work of Siegel and White (1975), Montello (1998) proposes an alternative model regarding the acquisition of spatial knowledge. He argues that rather than learning information regarding landmarks and routes at separate stages, this information is learnt concurrently. Consequently, as each knowledge type, landmark, routes and survey, develops simultaneously, repeated exposure to an environment improves accuracy as a series of refinements, a quantitative, rather than qualitative, shift between knowledge types occurs. Montello argues that the only qualitative shift which occurs is the joining of separately learnt environments into an organised representation, for example, combining knowledge of two previously learnt neighbourhoods into one spatial understanding of the overall town. Finally, Montello highlights that spatial information is stored in multiple formats concurrently. Individuals maintain route dependant knowledge in addition to the Euclidean metrics suggested by Siegel and White. Montello argues that individuals with equal exposure still differ in their knowledge of the environment due to individual differences in spatial knowledge. Despite criticisms, Siegel and White's theory remains a useful contextual tool regarding the categorisation of spatial knowledge and is still influential today. Isikawa and Montello (2006) note that despite clear limitations and contested empirical support, researchers have been unable to replace Siegel and White's theory with a working alternative theoretical framework. A key advantage of Montello's (1998) framework is the view of continuous development, which is based on exposure rather than multisensory integration. Within desktop digital environments, users do not receive body movement cues and are reliant on visual cues. If Siegel and White framework is accepted, users should not be able to develop route and survey knowledge. The importance of body movement cues and idiothetic feedback in remaining orientated will be discussed further, however prior to this it is important to consider how an individual tracks their position within an environment during actual or perceived motion, a process referred to as spatial updating (Reiser, 1989).

Spatial Updating

As we move, our egocentric relationship with the environment constantly changes. If an individual experiences, or perceives motion, they are required to reorient themselves via the use of constant static cues relative to their previous location. This process of reorientation is referred to as spatial updating (Reiser, 1989). For example if an individual is sitting facing a computer and turns to the right to answer the door, the computer is now on the individual's left. Evidence, (Reiser, 1989; Farrell & Robertson, 1998) suggests that spatial updating is an automatic cognitive process which operates to ensure that an individual's egocentric reference matches their current alignment. Within traditional real world environments, spatial updating acts to ensure that individuals retain knowledge of their local environment, do not collide with near objects as they move and enables the tracking of distant targets. Visual cues are not, however, required for automatic spatial updating, with blindfolded participants being highly accurate at spatial updating tasks (Farrell & Robertson, 1998). Evidence suggests that vestibular and proprioceptive information are central in enabling accurate spatial updating processes to occur (Lackner & DiZio, 2005). In an extensive literature review, Lackner and DiZio (2005) argue that in situations where visual information is available, it acts to reinforce and support vestibular information, available from a variety of sources, including body position and ocular muscle positioning, rather than being the primary driver of this information. Vestibular and other body movement cues are not however available when examining digital spaces, consequently tracking object locations within such spaces is potentially a greater challenge than within the real world. Indeed, Witmer, Bailey, Knerr, and Parsons (1996) demonstrated that the acquisition of survey knowledge and orientation accuracy is reduced within digital compared to real world environments.

Importance of Locomotion

Research has demonstrated that individuals can easily track items within their local environment as they move, even when blindfolded (Reiser, 1989; Presson & Montello, 1994; Farrell & Robertson, 1998). However, if participants are asked to imagine a rotation, therefore lacking any idiothetic information, before being asked to point to where a target would be, they experience great difficulty and make significantly greater rotational errors. In an investigation of automatic spatial updating, Farrell and Robertson (1998) compared pointing accuracy of 15 blindfolded participants across four conditions, updating, imagination, ignoring and control. In the updating condition, participants were rotated to face a different direction. In the imagination condition, participants did not rotate but were told to imagine that they had, and point in the direction the target would be. In the ignoring condition, participants were rotated but told to ignore this rotation. In the control condition participants were rotated both clockwise and anticlockwise, so that they ended in their starting location. Farrell and Robertson found that participants were least accurate and had greatest latency in the imagination and ignoring trials. Farrell and Robertson (1998) argue that this suggests that individuals automatically update their spatial orientation without attentional focus (Wan, Wang & Crowell, 2009). They argue that the greater latency recorded was a consequence of participants having to cognitively "undo" the experienced rotation, from their current position back to the starting point. If spatial updating was not automatic, they argue that no such correction would be needed. This finding highlights the importance of body movement, both real and imagined, within spatial updating, as participants who were physically rotated recorded the greatest accuracy and smallest latency. This suggests that the vestibular and idiothetic cues provided by the rotation were beneficial.

The importance of body movement cues has been supported by research comparing orientation specific learning within real and virtual environments. Sun, Chan and Campos (2004) compared orientation specificity when learning from the real world, a virtual representation of the environment or a map. They found that participants learnt orientation free representations of an environment during active navigation, both walking and, to a lesser extent, interactions with the virtual representation of the environment.

However, when participants learnt environmental layout from a map, orientation specificity was observed. Sun et al. suggests that orientation specificity is a consequence of the limited sensorimotor stimuli available when using maps. The finding that participants recorded greater orientation specificity within the virtual compared to the real environment suggests that limited motor stimuli directly impacted participants' ability to learn about their environment when using digital spaces. Overall this suggests that body movement cues are influential in enabling individuals to remain oriented.

Spatial Updating within Digital Environments

Body movement cues play an important role within orientation; however these cues are not available within digital environments. Rather, individuals must rely on visual cues to track changes (Hartley, Trinkler & Burgess, 2004). Early research (Rieser, 1989; Farrell & Robertson, 1998, Wraga, Creem-Regehr, & Proffitt, 2004) highlighted the importance of physical motion within spatial updating, either via the use of imagined movement (Farrell & Robertson, 1998) or rudimentary digital environments (Wraga, et al., 2004). More recent research (Riecke, Cunningham & Bulthoff, 2007; Wan, Wang & Crowell, 2009), however, has begun to challenge this finding. Riecke, Cunningham and Bulthoff (2007) explored the sufficiency of visual cues for spatial updating when exploring within a virtual environment. Using a pointing paradigm, participants were seated within a motion platform, and witnessed a tour of a city. The study used a 2 X 2 mixed design, whereby participants either had or did not have access to physical motion cues provided by the platform, and either visual stimulus provided by a pre-recorded video tour of a city or matching optic flow patterns but no distinctive images and cues. Reicke et al., found that participants provided with the realistic tour of the environment were able to engage in automatic spatial updating, regardless of whether they had access to physical motion cues, suggesting that visual cues were sufficient for spatial updating.

They found however that optic flow patterns were not sufficient to induce automatic spatial updating, regardless of the presence of motion cues. These results contrast with the view that physical motion is a pre-requisite for effective spatial orientation. Participants provided with physical motion cues were unable to effectively update their position, whereas those with no physical motion cues, but visual cues were able to engage in accurate updating. Expanding on this work, Wan, Wang and Crowell (2009) asked participants to learn the layout of items within a room and within a virtual kitchen, superimposed upon the environment using a head mounted display. Participants pointed to targets whilst blindfolded and stationary. They were then seated on a swivel chair and asked to point in the direction of targets from either the virtual kitchen or the room. It was found that individuals were better at updating the virtual environment than the real world, producing less rotational errors. These findings suggest that participants were able to update their location even within an unreal environment, counter to what would be expected based on the results of Farrell and Robertson. It should be noted however that Wan et al. used an immersive head mounted display and still required individuals to make a physical turn, giving participants some degree of vestibular feedback. Wan et al. note that despite providing an unrealistic space, participants were still able to accurately update their position within the immersive environment using just visual cues. It should be noted that both Reicke et al., and Wan et al., used either large scale display screens to create an illusion of immersion (Reicke et al.) or a head mounted display (Wan et al.), rather than a desktop computer environment which may provide a less visually rich and immersive scene.

Summary

From the research cited, it is apparent that the development of spatial knowledge is a difficult process; however this can be supported by the use of active navigation experience and landmark cues. Research has provided a mixed view of the differences between orientation and spatial updating within the real world and digital environments, with numerous researchers (Reiser, 1989; Presson & Montello, 1994; Farrell & Robertson, 1998) highlighting the importance of physical motion cues in successful spatial updating. Landmark cues are however also important in the maintenance of spatial orientation. The loss of landmark cues is associated with disorientation and confusion regarding an objects location (Reicke et al., 2007). As newer research (Reicke et al., 2007; Wan et al., 2009) has begun to suggest, spatial updating is possible within digital environments without access to idiothetic cues, but not without salient visual cues.

Whilst research (Reicke et al., 2007; Wan et al., 2009) has begun to identify that spatial updating is possible without the use of vestibular and idiothetic cues, providing these cues has been demonstrated to aid in the acquisition of spatial knowledge. Based on the work of Reiser, (1989), Presson and Montello, (1994) and Farrell and Robertson (1998) it is clear that body movement cues can facilitate spatial task performance. Although there is currently a lack of studies which directly compares spatial knowledge gained within the real world and virtual environments, it is clear that the acquisition of spatial knowledge from either source is not a trivial task. Efforts to boast participants understanding within either environment would therefore be beneficial. Due to the rapidly developing nature of and the growing availability of virtual environments, it makes sense to explore this environment type.

The next section of this review will focus on alternative digital environments, specifically geovisualisations, how they work, including alternative zoom systems, differences in symbolisation and the orientation within these environments.

Geovisualisations and Digital Maps

As we have seen within the previous section, accurate orientation within digital environments which lack idiothetic and vestibular cues might pose challenges. So far the research considered has largely looked at the development of spatial understanding within real environments (Siegel & White, 1975; Montello, 1998), and realistic virtual environments (Reicke et al. 2007; Wan et al., 2009). Realistic virtual environments are not the only spatial environments which have emerged as a response to technological developments, cartography has been revolutionised by the development of digital mapping. A radical shift has also occurred regarding the size and attributes of the map making and map using community (Goodchild, 2004). With the development of free-to-use web based services, including Google Maps, Google Earth and open source software such as OpenStreetMap, the entry barriers to low level geographic information science (GIS) analysis has become much reduced, for example, individuals can now easily use web based route planners. These tools have revolutionised the use of geovisualisations, interactive data maps (MacEachren & Kraak, 2001), by offering easily sharable visualised data to users that otherwise would not have access to this information (Harrower & Fabrikant, 2008). Although not true GIS systems as defined by Tomlinson (2003) or Longley, Goodchild and Maguire (2005), these systems have allowed users to easily obtain geographic information which was not available previously. Consequently, the number of users of these services has eclipsed traditional GIS systems, which were limited to a small number of professional users (Miller, 2006). This shift has enabled a greater variety of individuals to become active users, completing low level GIS analysis within web browsers, such as route planning. With this change, maps could be produced by amateurs, a change popularised as “neogeography” (Turner, 2006). This trend however has not always been seen as positive. Wood (2003) suggests that cartographers and experts in map design are becoming increasingly marginalised by mediocre geovisualisations. Wood however suggests that the shift towards the amateur user offers cartographic tools to a greater proportion of society, potentially supporting a greater use of geovisualisations. Regardless, it is clear that the number of available geovisualisations has, and continues to grow at a rapid rate (Midtbø & Nordvik, 2007).

Alongside this transition in users, maps have evolved from static, paper based navigation devices to dynamic, digital tools, which users can interact with and explore, using controls including pan and zoom. As noted, digital maps are increasingly used as data display media, allowing users to combine data with a map to produce geovisualisations (Wood, Dykes Slingsby & Clarke, 2007). Geovisualisations comprise of two fundamental components, a base map, displaying the underlying geography, be it a street map or aerial photograph, and at least one data layer, which, using a stylised symbolisation, presents the desired data and information. For example, a map showing cafes in a city could use a road map as the base map and cup icons as the data layer. Estimates suggest that of all data visualisations available online, approximately 40% are map based (van der Vlist, Ayers, Bruchez, Fawcett, & Vernet, 2007). Despite the relative popularity of web based geovisualisations, how users are interacting with these environments is not fully understood. With the recorded orientation difficulty identified within studies examining other spatial environments, can users remain oriented within geovisualisations or are the orientation difficulties seen within other virtual environments repeated or even magnified?

Despite an overall awareness of the importance of the end user (Nivala, Sarjakoski & Sarjakoski 2007), this is rarely discussed within formal literature (Nivala, Brewster & Sarjakoski 2008). Consequently few studies have examined the common difficulties within these environments, specifically the role of orientation. Numerous researchers have noted the requirement for study into the use of geovisualisations (MacEachren et al., 1999, Slocum et al., 2001). Successful use of geovisualisations requires the user to effectively navigate and orient within the environment whilst simultaneously understanding the represented information, before relating it back to the real world (Fuhrmann & MacEachren, 2001). Research suggests that increasing levels of interactivity, including additional navigational tasks, can act to confuse users (Hanson & Wernet, 1997), who struggle to integrate multiple layers of data and spatial information within the same interface. This confusion can result in a feeling of disorientation (Darken & Sibert, 1996). Within an information retrieval task, Darken and Sibert (1996), using a rudimentary digital environment, found that disorientation can dramatically increase search time, especially if insufficient landmarks are available.

Digital Cartography

The increasing number and availability of geovisualisations can be seen as part of the ongoing digitisation of geography, a process which started with the development GIS. GIS tools enabled the production of editable, data-driven geovisualisations. Olson (1997) labelled this development as *"new cartography"* (*p*572) and stressed that due to advantages offered and changes required by the newer systems, both by developers and users, "new cartography" would be unable to draw upon principles established for traditional paper cartography. A stance supported by Koua and Kraak (2004). This techno-optimism is matched by scientific and cultural acceptance of the importance of digital systems (Pedersen, Farrell, & McPhee, 2005).

Geovisualisations differ from traditional paper maps in two main regards. The first is the primary aim of the tool. Paper maps have been traditionally used as navigational aids, to assist users in reaching set goals from a known location. In contrast, geovisualisations are primarily used to explore spatial information, not to aid navigation.

The second key difference between geovisualisations and traditional paper maps is the increased level of interactivity which is required to use geovisualisations (Mitchell, 2005). Users must be active in their search, using controls such as pan and zoom to display otherwise hidden information.

Haklay and Zafiri (2008) suggest that the rapid growth and potential for web-based geovisualisations must be balanced with evidence which assess the impact, usefulness and usability of available tools. A key issue highlighted by Harrower and Sheesley (2005) related to geovisualisations is user disorientation, within a literature review drawing upon research relating to the use of both non-spatial visualisations and geovisualisations, they found that issues related to disorientation is a common difficulty. Harrower and Sheesley (2005) suggest addressing this issue via the use of a greater number of landmark cues, specifically they argue that there needs to be a greater connection between the differing zoom levels of geovisualisations so that landmarks are common and visible at all zoom levels. Harrower and Sheesley refer to this as a need for local-global orientation cues. They do note however that the exact number of these cues or the form they should take varies between geovisualisation and vary with the characteristics of the user, as such clear design principles are not possible. Although fundamentally geovisualisations require users to interact or witness change within the display, due to fundamental differences in user experience and geographical knowledge, aids that help novice users may be harmful to the interactions of experts.

Representing geographic space on a computer screen requires abstraction from reality. It is not possible to see a detailed view of the entire world within a single computer screen, *"interfaces… supply users with very small screens to view large complex information spaces"* (Schaffer et al., 1996, *p*163). Numerous alternative navigation controls have been developed to help users explore and interact with geovisualisations, however pan and zoom has become the dominant navigation system within geovisualisations (You, Chen, Liu, & Lin, 2007). Pan is the ability to explore an area at a set altitude, whereas zoom allows users to change altitude, magnifying or demagnifying a region. As a user zooms, a greater amount of panning is required to examine the same size region (Furnas & Bederson, 1995). Geovisualisations with extensive navigational freedom present a greater difficulty to operate than traditional text documents which rely largely on linear navigation, for example a scrollable word document (Jones, Jones, Marsden, Patel & Cockburn, 2005). By increasing navigation complexity, there is a greater potential for user disorientation (Smith & Marsh, 2004) as users can lose track of where they are within the wider space. Jul and Furnas (1998) argue that at extreme levels of zoom magnification, there is a potential for a lack of orienting features. As users zoom out of the map, landmark cues which can be used to track an individual's position within the display become so small that they are no longer visible. Consequently, users can lose track of their current position and become disoriented, reducing the effectiveness of the geovisualisations as an information display tool. Should a user become disoriented they are likely to be unwilling to explore their environment and interact further with any data concurrently presented (Peuquet, 2002).

Interactivity and Controls

By introducing navigable information spaces, users of geovisualisations can examine a particular area of interest whilst bypassing areas of limited perceived value (Bederson & Hollan, 1994). The following discussion is designed to introduce the reader to the variety of zoom functions that are used within geovisualisations. Due to their inclusion within Google Earth (Midtbø & Nordvik, 2007) and Google Maps (Cockburn, Karlson, Bederson, 2008), most time will be spent discussing geometric and semantic zoom. This discussion does not intend to introduce the reader to the technical specification and implementation of these techniques, which is beyond the scope of the present discussion.

Zoom interactions

Zoom is a key control impacting user interactions with geovisualisations (Cockburn & Savage, 2003), and can be implemented in a variety of ways. Two of the more common zoom functions are geometric and semantic zoom. Each of these techniques has associated costs and benefits. Geometric zoom presents zoom as a continuous change, (Buring, Gerken & Reiterer, 2006), which is completely controlled by the user; motion is a continual and fluid process without disruption. This technique is common within visualisations and virtual worlds that encourage active navigation and exploration, such as Google Earth. The use of geometric zoom may act to reduce the level of abstraction between the user, visualisation and the real world, promoting a more natural experience. Geiger, Reckter, Dumitrescu, Kahl and Berssenbrügge (2009) suggest that geometric zoom can be considered realistic, based on the behavioural metaphor of traveling towards a target to reveal clearer detail. As Gale, Golledge, Pellegrino and Donerty (1990) suggest that as the most effective way to obtain spatial knowledge is through experience and movement, geometric interfaces help users remain oriented due to reduced abstraction. Cockburn, Karlson and Bederson (2008) argue that geometric interfaces remove the temporal separation between commands and actions, freely allowing users to move through a space. They suggest that this free movement should help users to develop a mental map as they explore (Tolman, 1948), facilitating future use. Geometric zoom is however highly system intensive, making it unsuitable for users with limited computer facilities, for example poor web connections or low graphics capacity. Despite being beneficial from an orientation perspective, geometric zoom has largely been eclipsed by the use of semantic zoom as the main method implemented within geovisualisations, primarily due to the inclusion of semantic zoom within Google Maps and OpenStreetMap.

Rather than simply changing an objects size, a semantic zoom (Perlin & Fox, 1993) alters all properties of the displayed information depending on user interactions and the space available within the display (Perlin & Fox 1993, Buring, Gerken & Reiterer, 2006). As a consequence, different information is displayed to the user at each zoom level. Semantic zoom allows for greater information density, as only relevant information is displayed, all superfluous and non-essential information can be removed, reducing visual clutter, *"any aspect of the visualization that interferes with the viewer's understanding of the data"* (Peng, Ward & Rundensteiner, 2004, p89). Harrower and Sheesly (2005) argue that this method of "detail on demand" (Shneiderman, 1996) encourages users to actively engage with visualisations, as key information is only available at certain levels of the display. The use of semantic zoom may however increase the likelihood of disorientation. Due to information appearing and disappearing, users may become confused as to where they are within the display, a factor compounded due to a lack of consistent landmark and orienting cues throughout all levels. Gahegan (1999) notes that maintaining orientation is one of the main challenges in the use of geovisualisations, a problem increased by tools that promote a navigational experience disjoint from everyday experiences, including semantic zoom. Few studies have examined disorientation explicitly within geovisualisations. One goal of the current research is to examine whether the additional information provided within geovisualisation assist users in remaining oriented or act to further confuse users as regards their current location. It should be noted that despite the negative impact semantic zoom can have on users' ability to remain oriented, semantic zoom is necessary within symbolised geovisualisation to reduce data crowding and to increase the potential information density (Krygier & Woods, 2011).

Regardless of the underlying technique, zoom can be used to reduce the amount of panning required to explore a region. This can help reduce user disorientation associated with excessive panning (Igarashi & Hinkley, 2000). Igarashi and Hinkley (2000) demonstrated that when panning, the rapid rate of change is impossible to accurately track, users can therefore quickly lose track of their current position and become unable to return to their starting location. The inclusion of clear orienting features at all zoom levels within a geovisualisation should reduce this problem. A key issue however is how these features should be presented so that they are supportive but do not disrupt the overall use of the system. As little work has been done to address the extent of the problem, there are few pieces of empirically supported evidence regarding potential solutions. With the added presence of data as part of geovisualisations and the implementation of semantic zoom, an appropriate solution is unclear.

One investigation into how effective users were at tracking their position within a digital map, focussing on the use of differing zoom systems, is provided by Midtbø and Nordvik (2007). They explored the role of animation within zooming on participants' ability to accurately plot the starting position of a non-visible marker. They developed a short online application which presented participants with a marker within a geovisualisation which would then disappear as the geovisualisation automatically zoomed out. Participants were required to report the markers original location within the outzoomed view of the geovisualisation. Participants completed a practice session before proceeding to the main task. Participants completed the task using both geometric and stepwise zoom system. Within the geometric condition, the screen fluidly zoomed within the geovisualisation, simply making targets appear larger. In contrast, the stepwise zoom possessed greater step changes, and each zoom step into and out of the map was presented with a short pause. Midtbø and Nordvik (2007) found that stepwise changes were more difficult for participants to track, as shown by participants making greatest error when asked to plot the marker's location within this display. This error suggests that, when being a passive observer, a geometric zoom is better for reducing disorientation and facilitating understanding regarding object locations relationships. Due to the use of semantic zoom employed within geovisualisations, stepwise changes are frequently encountered. This suggests that users are likely to experience disorientation. As this study was based on a short pre-recorded application, it remains unclear whether interactivity would have influenced results. MacEachren and Kraak (2001) have argued that interactivity is key within the use of geovisualisations and subsequently the lack of interactivity within this study may have impacted on the results. Additionally, although an online investigation, participants were predominantly members of a specialist Norwegian web forum dedicated to the field of geomatics, or delegates within a dedicated cartography conference. Many participants therefore had considerable experience of using interactive maps and geovisualisations. Further work is needed to examine whether this finding is ecologically valid when dealing with a more heterogeneous user population who lack this specialist experience. The level of error recorded within this study, even among expert users however is compelling. Overall Midtbø and Nordvik (2007) provide persuasive evidence that users' can struggle to accurately track a target location within geovisualisations. As tracking objects location is central in maintaining orientation (Reiser, 1989) this suggests that users of such systems are vulnerable to becoming disoriented. Due to the importance of orientation as a precursor to understanding information within any given environment (Kelly, McNamara, Bodenbeimer, Carr &

Rieser, 2009), potential difficulty in maintaining orientation can disrupt the use of information shown within the display.

Representing Data on Thematic Maps

The purpose of geovisualisations is to display spatial data (MacEachren & Kraak, 2001; Haklay, 2010). In addition to problems relating to disorientation, another potential area of difficulty is whether users' adequately understand the symbolisation used within the geovisualisation. Whilst the understanding of symbolisation has been investigated, there is a lack of evidence regarding newer symbolisation techniques, including the clustering displays commonly used within Google Maps (Mahe & Broadfoot, 2010), and symbolisation within dynamic geovisualisations. Rather, research has remained focused on interface controls and base map displays whilst not fully considering the role data can play in users' interactions (Nivala, Brewster & Sarjakoski, 2008). With the development of dynamic geovisualisations, symbolisation techniques are changing so that what is displayed may not be correctly interpreted by users. Examples include the dynamic grouping of points within a cluster display and the use of coloured categorical overlays apparent within heat and choropleth maps.

Lowe (2003) investigated understanding of symbols within static and dynamic meteorological maps. He recruited 24 undergraduates with no previous experience using meteorological maps. After a brief training session, half of the participants were presented with a static meteorological map and half with an animated meteorological visualisation. Participants were asked to redraw the map, making predictions regarding the changes that were likely to occur after 24 hours. Lowe found that participants extracted information based on symbols with high visual salience and distinctive appearance, regardless of relative value. Lowe theorised that due to a lack of prior experience, participants lacked sufficient knowledge to fully understand the available information. These findings provide evidence that understanding is impacted by the visual properties of map artefacts more than the information they portray. Fabrikant and Goldsberry (2005) note that visual salience of symbols is essential in understanding the use of any cartographic displays, especially when examining dynamic maps. Extending this research, it is possible that users may struggle to interpret the meaning of data within geovisualisations due to limited experience with the symbolisation.

A key limitation of the use of symbols within geovisualisations is data overcrowding. This problem occurs when numbers of symbols on a map rise to a level where they obscure additional points and the underlying map, acting to reduce the overall clarity (Krygier & Woods, 2011). To reduce data crowding, amalgamation effects are frequently used whereby nearby symbols and markers are grouped. An example commonly encountered within geovisualisations is gridded cluster mapping (Mahe & Broadfoot, 2010). Cluster mapping works by dividing the map into an equal sized grid containing multiple squares (Figure 1.1), data points within each square are then grouped and replaced with a single symbol, usually marked with the number of points it contains (Figure 1.2), with the potential to display different size of coloured symbols based on this number. Thus clusters with more than 100 points may become larger and a different colour from clusters containing less than 100 points. Clustering is recalculated at each zoom step into or out of the map (Mahe & Broadfoot*,* 2010), utilising a form of semantic zoom (Perlin & Fox, 1993). The catchment area of each cluster point is not visible to the user. As a consequence of the cluster algorithm, cluster markers and data points actively appear, disappear and migrate as the user zooms. A larger scale view of the changes implemented by the use of cluster mapping can be seen within figures 1.3 and 1.4. As the original location of data within the geovisualisation is not represented at higher levels of zoom, the location of displayed clusters may not accurately represent the underlying data.

For example due to the arbitrary placing of the grids within geovisualisation, data may become skewed at higher zoom levels where the individual is unable examine individual data points. In addition, as a consequence of semantic zoom and a lack of consistent information between the layers, users may become disoriented as they zoom between the map layers (Midtbø & Nordvic, 2007; Jul & Furnas, 1998). As the user zooms, both the data layer and the base map changes, resulting in few consistent landmark or reference points.

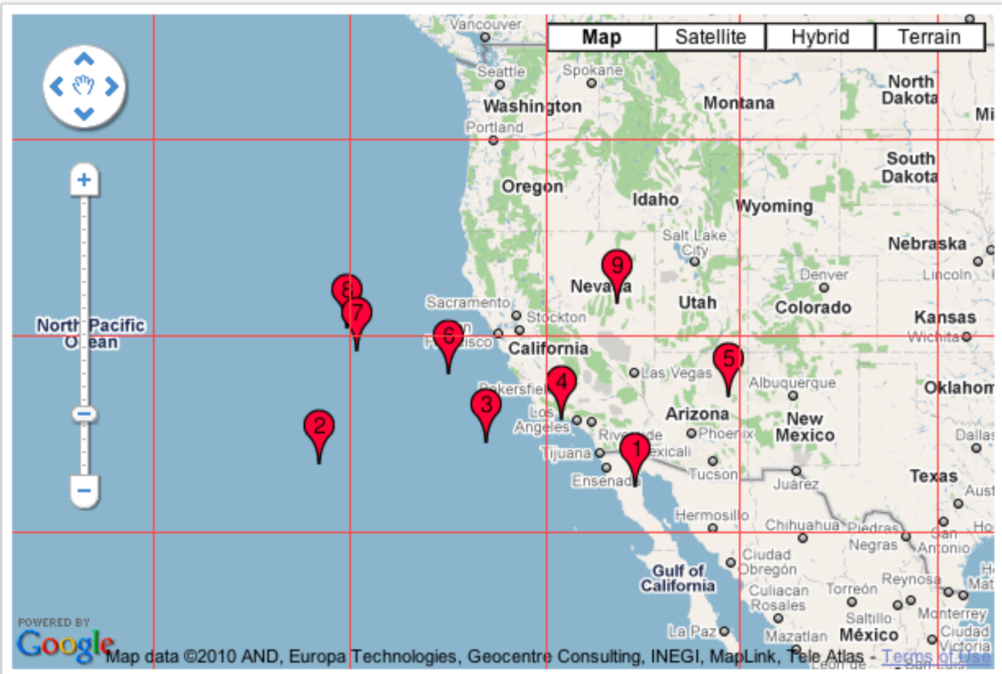


Figure 1.1. Example map showing raw data prior to the application of the clustering algorithm. The red grid lines show the regions that will be grouped together by the clustering algorithm. These grid lines are however not visible to the end users. Taken from Mahe and Broadfoot (2010).

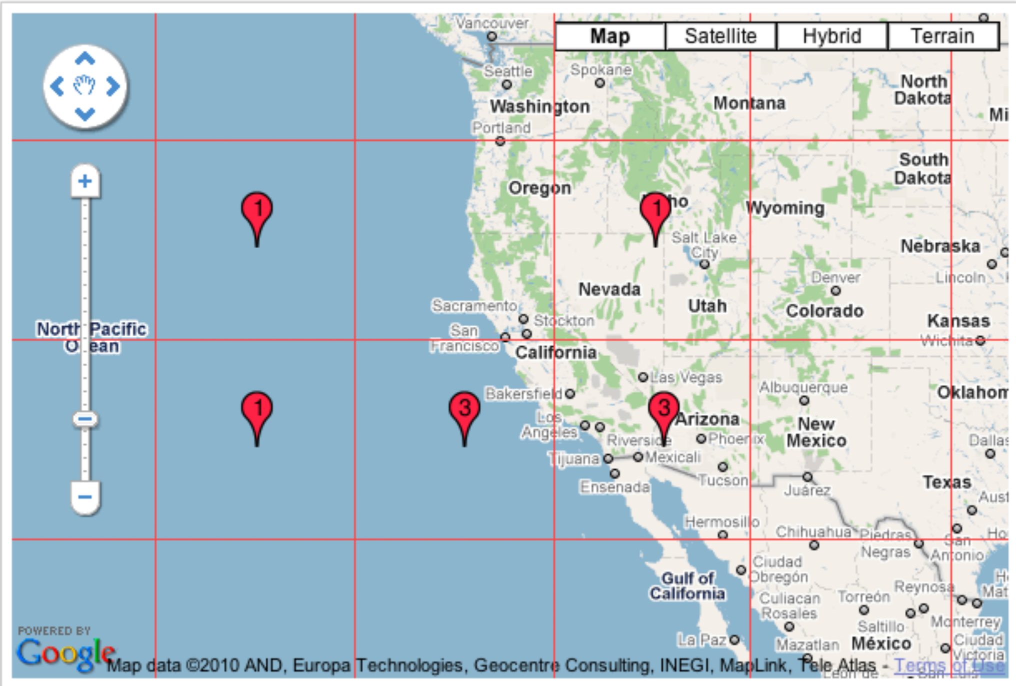


Figure 1.2. The same data as presented within Figure 1.1 once the cluster algorithm has been applied. It can be seen that it is no longer possible to determine the original location of the starting data. The grid squares are not apparent to the end user of the geovisualisation. Taken from Mahe and Broadfoot (2010).

Figure 1.3. Example map showing raw data prior to the application of a clustering algorithm. Taken from Mahe and Broadfoot (2010).

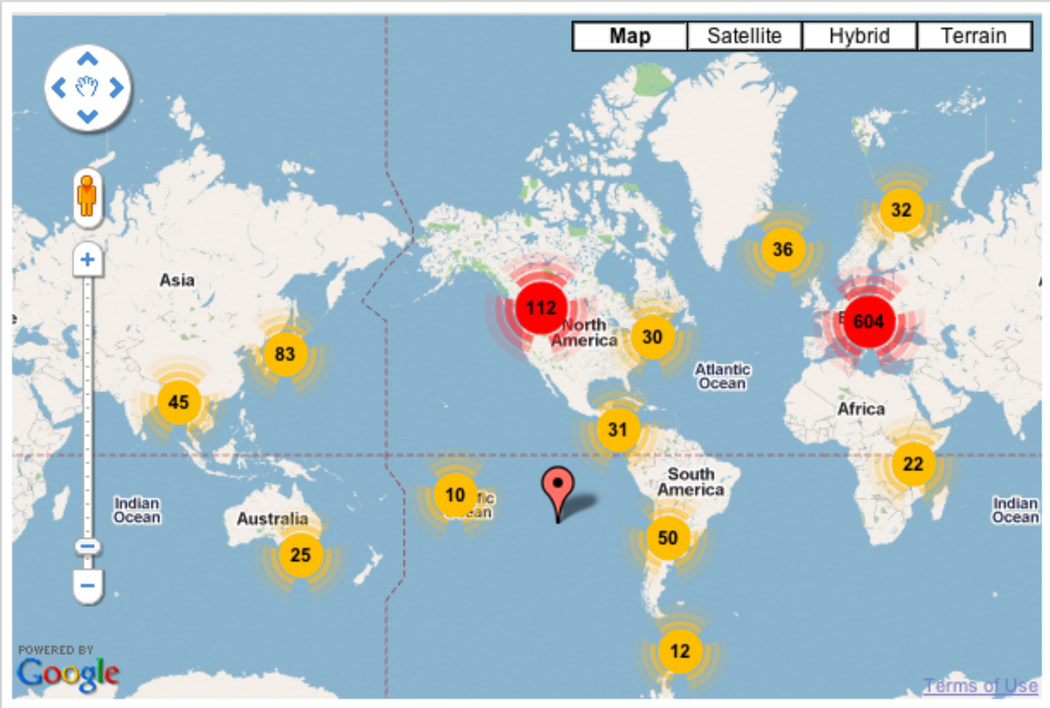


Figure 1.4. Example map showing the same data presented within Figure 1.3, however with a clustering algorithm applied. Clusters larger than 100 points are both larger and represented by a different colour marker than clusters containing less than 100 points. Taken from Mahe and Broadfoot (2010).

An alternative common geovisualisation type that can be encountered is a density choropleth map. Density choropleth geovisualisations can be used to display any spatial data, for example Figure 1.5 displays the percentage of the population within UK counties with a Level 4 or higher qualification. This would not be possible with the use of a cluster geovisualisation, which display the number of things that occur. Density choropleth geovisualisations however can also be used to display the number of occurrences within a given geographical area, for example the number of restaurants or the number of crimes committed within a region. In this regard, density choropleth geovisualisations can be used to display the same data as a cluster geovisualisation. Although not displaying raw data, choropleth maps are advantageous should the geovisualisation user be interested in changing trends, as areas can quickly be compared (Haklay, 2010). Density choropleth geovisualisations can also be advantageous as the lack of symbols can act to reduce visual clutter (Peng, Ward & Rundensteiner, 2004), consequently obscuring less of the underlying base map, meaning that landmark cues are more likely to remain visible, potentially facilitating a users' ability to remain oriented. Evidence does suggest that users often regard density choropleth plots highly due to ease of use and overall simplicity (Boscoe & Pickle, 2003).

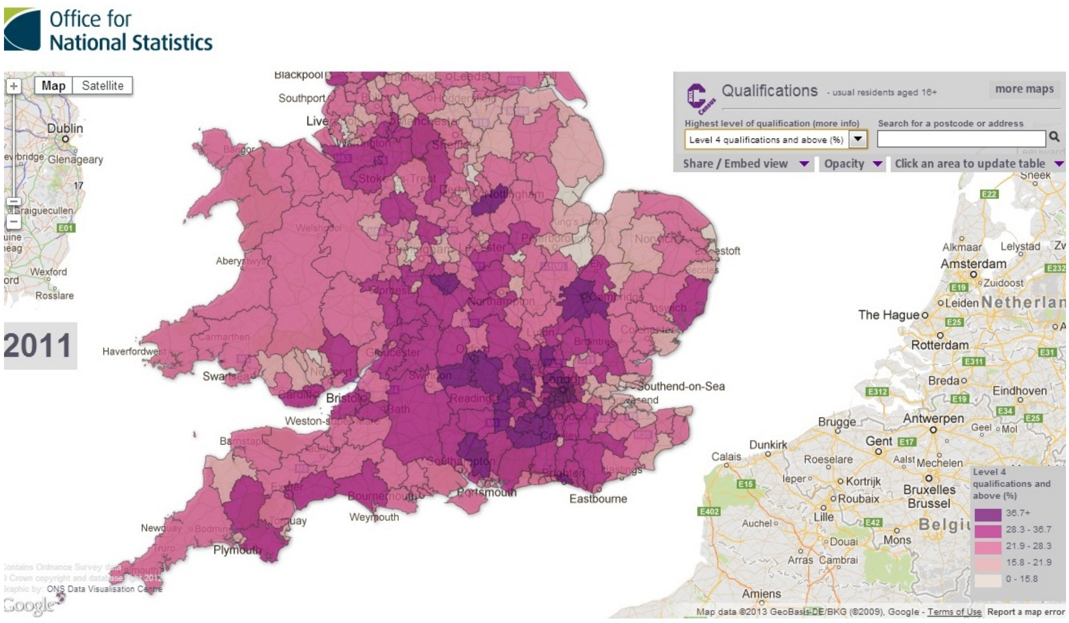


Figure 1.5. An example density choropleth map, taken from Office of National Statistics, displaying the percentage of the population with a level 4 and above qualification. It can be seen that the raw data is not visible, but rather the relative density of an event is compared across regions.

Summary

In this section it is hoped that readers were introduced to digital cartography, zoom techniques and introduced to different symbolisation used within geovisualisations. Despite the rapid technical developments that have occurred, developments within digital cartography have largely been dominated by a technological deterministic approach (Hildebrandt, 2008). Technological developments have shaped the creation of digital maps and geovisualisations, as opposed to the need of users. Fabrikant and Josselin (2003, cited in Harrower & Fabrikant, 2008) suggest that the rapid speed of technological developments has led to a situation whereby researchers are forced to catch-up, with the rate of technical change outpacing the developments of newer cartographic theory. The more recent calls for increased investment in usability (Harrower, 2007; Nivala, Brewster & Sarjakoski, 2008) can be seen as an acknowledgement of this problem. Harrower (2007) summed the use of geovisualisations stating *"When it comes to animated maps, the bottleneck is no longer the hardware, the software, or the data – it is the limited visual and cognitive processing capabilities of the map reader"* (*p*349). By returning research focus onto processes which facilitate successful user interactions rather than the limitations and potential of newer technology, it is hoped that pro-human geovisualisations can be developed. Research is needed to examine whether participants are able to remain oriented within commonly available geovisualisations.

The next section of this review will link geovisualisations with the virtual environments explored previously. It is proposed that commonly encountered virtual environments and geovisualisations which individuals are exposed to are nested, that is comprised of multiple distinct aspects and multiple spatial reference frames (Wang & Brockmole, 2003). For example, virtual models frequently involve entering and exploring buildings, exposing users to interior and exterior spaces, similar to real world nested environments. Similarly, it is proposed that the zoom function within geovisualisations can be seen as moving between multiple spatial reference frames. This can be seen as a clear departure from static maps, which are not nested representations.

Nested Environments

It has been seen that remaining oriented within digital environments and geovisualisations is a challenge to users. Although the lack of idiothetic and vestibular cues may partially account for some of the recorded difficulty, an additional element that links these types of environments is that they are nested. Spatial environments do not exist in isolation, but rather are part of larger spatial contexts (Wang & Brockmole, 2003). Real world examples of this include rooms within a building, a building within a university campus or a university campus within a city. These environments are not independent of each other, movement within one aspect of the environment, for example the room within the building, changes an individual's spatial relationship with not just their immediate environment, items within the room, but also other elements in the larger environment, for example the location of items within the university campus.

Work examining orientation within nested environments has focused primarily on real world environments. Wang and Brockmole (2003) investigated spatial updating within nested environments, specifically, a room within a university campus. After learning the locations of key targets within both the room and the wider campus, blindfolded participants were required to track key objects within either the room or the campus. Participants were then required to point to non-visible objects outside of the room within the larger environment. They found that although participants could maintain orientation within the local environment of the room, participants struggled to accurately track and update locations within the external setting of the wider campus. Wang and Brockmole argue that this finding suggests that each sub-environment within nested environments is updated independently rather than simultaneously as part of a gestalt whole. The room and the campus were separate spatial reference frames. It is possible that a failure to adequately update position within multiple spatial reference frames is responsible for the high levels of disorientation seen within the geovisualisation tasks discussed previously, for example Midtbø and Nordvik, (2007). Participants struggle to track their position across the multiple layers of the geovisualisation, losing sense of the marker's location during the tour. Similarly, Harrower and Sheesley's (2005) recommendation for consistent landmarks between layers within geovisualisations hints that similar processes are occurring to those seen within nested environments. Geovisualisations are highly complex digital environments, and as Smith and Marsh, (2004) suggest, as complexity increases so does the potential for users to become disorientated. An individual experiences disorientation when they lose track of their current location relative to a wider space (Reiser, 1989, Farrell & Robertson, 1998). Difficulty in updating multiple reference frames, be it the external and internal spaces of a digital building or the different layers within a geovisualisation, may result in the individual failing to learn the spatial relationship between locations, consequently failing to develop an integrated mental representation (Tolman, 1948).

Technical developments over the last decade have enabled a rapid growth in the availability of digital spatial environments, including digital worlds and geovisualisations. However questions remain regarding how individuals are remaining oriented within these environments and whether this task can be supported and facilitated with targeted interventions. By focusing on the role of orientation, it is hoped that clear and consistent links can be observed between the different types of spatial environments that individuals are exposed to and use on a regular basis. Orientation and navigation are frequently viewed as a secondary concerns by both users and developers (Bederson, 2011), as they frequently are not the primary objective of users interactions. Despite this, these activities remain essential for successful interaction, allowing the users to complete other tasks.

Primary Research Questions and Overall Aim

This thesis will attempt to address the following key research questions:-

1. Is disorientation encountered when using geovisualisations?
2. Can participants effectively orient within virtual environments?
3. Can interventions, both directly applied to the environment and psychological manipulation, be used to influence participants' ability to remain oriented within virtual environments?

Thesis Outline

Two key research strands are explored within this thesis, orientation within geovisualisations and orientation within virtual environments.

Chapter 2 investigates the cues and techniques which participants are using within the symbolic environments of geovisualisations. Specifically, Chapter 2 examines participants' ability to track objects and remain oriented within two geovisualisations, a cluster geovisualisation and a heat geovisualisation. This chapter seeks to explore whether participants ability to remain oriented differs between multiple geovisualisations. This is examined within a large-scale web study, presenting participants with a series of pre-recorded video tours. Results suggest that, regardless of geovisualisation type, orientation difficulty was encountered, impacted participant performance and influenced participants' ability to understand the information which was presented within the geovisualisations. Building on this initial exploration, orientation within geovisualisations is further explored within Chapter 3. Chapter 3 presents a study whereby participants were invited into the laboratory to use and orient within alternative geovisualisations. Chapter 3 expands on Chapter 2, as in contrast to Chapter 2, whereby participants were required to watch passive video tours of geovisualisations, participants within Chapter 3 were in control of their own movement. Chapter 3 therefore examines the role of interactivity in the use of geovisualisations. Findings once again highlight the difficulty users' face in remaining oriented within geovisualisations.

Although it is apparent from the results in Chapter 2 and Chapter 3 that users are struggling to maintain orientation within geovisualisations, these studies are largely exploratory. Due to the exploratory nature of these studies and nature of exploring geovisualisations as large scale, multifaceted, complex digital environments, there are limitations to investigating general learning principles, especially regarding the cues which participants are using to remain oriented. To directly explore participants' ability to orient within digital environments, more controlled environments are required. This need is addressed within Chapters 4 – 7. In Chapter 4, participants' ability to remain oriented within a digital nested environment is explored. Specifically, this chapter investigates whether participants' ability to remain oriented within a digital nested environment could be facilitated by providing participants with orientation aids, either a map of the environment or salient colour band cues. It was found that the map was not of significant benefit, with participants provided with a map failing to record significantly reduced error rates compared to participants without a map. Unlike the addition of a map, however, providing participants with colour band orientation cues significantly reduced orientation error. In Chapter 5, the role of interactivity was explored to examine whether participants could still benefit from the inclusion of the colour band cues following a passive tour of the environment. It was found that participants with and without familiarity with the campus environment benefited from the colour band orienting cues, recording similar results to those seen within Chapter 4. Results from Chapter 5 therefore suggest that the colour band cues were effective at reducing orientation error following both active and passive explorations.

Despite results from Chapters 4 and 5 indicating that the colour band cues were effective, the underlying reasons for this facilitation remained unclear. Chapter 6 explores why the colour band orienting cues were effective at facilitating participants' ability to orient. Alternate layouts of the colour band cues were examined to investigate whether the mere presence of additional cues facilitated orientation performance or whether the way in which the colour band orientating cues were presented influenced participants' orientation error. It was found that the colour band orientation cues only reduced orientation error when they were constantly available and presented in an associative pattern with external targets. When the cues were arranged in a directional configuration and when the cues were only available on the inside of the building, orientation performance was not facilitated compared to a control group. Building on this, Chapter 6 also explores which cues participants use when making an orientation decision. When participants within the virtual building make an orientation decision they have access to both external landmark cues and the colour band cues. The cues which participants are using are explored to examine whether participant demonstrate a preference for either cue type. Results suggest that participants demonstrate a preference for the external cues. It was found, however, that when presented in contrast to the external cues, the colour band cues still influenced participants' orientation performance.

From the results of Chapters 4 – 6, it is apparent that direct modification of the environment can influence participants' ability to orientate. Chapter 7 explores whether participants orientation ability could be influenced, not only by the inclusion of additional cues, but also by manipulating participants' psychological state. Specifically, Chapter 7 explores the role of anxiety in orientation accuracy, investigating whether stereotype threat (Steele & Aronson, 1995) influences participants' ability to orient. Results suggest that when the colour band cues were present within the environment, both males and females were vulnerable to the stereotype manipulation, however when the bands were absent, only males were vulnerable. To examine the generalisability of the role of anxiety between environments, the influence of stereotype threat was explored both within the virtual building model examined previously, and within a virtual maze, with consistent results seen between both environments.

Chapter 8 presents a general discussion in order to integrate the findings identified within each chapter and proposes potential future research directions. Overall results demonstrate that despite technical advances, the ability to remain oriented is a great challenge to users of digital environments and geovisualisations.

Chapter 2

Experiment 1 - The Usability of Online Data Maps: A Web Based Investigation into Users Use of and Preference for Geovisualisations

As noted within Chapter 1, remaining oriented within virtual environments is a great challenge for users. This is true for both realistic virtual environments and geovisualisations (MacEachren & Kraak, 2001). Chapters 2 and 3 explore the extent to which users are able to remain oriented within and understand the information presented within geovisualisations in order to examine whether orientation and tracking position is a commonly encountered difficulty within these immersive environments. Chapters 2 and 3 focus on geovisualisations representing point data, specific incidents with a known location. Point data can be represented in a variety of ways as introduced within Chapter 1. Point data can be represented using choropleth techniques as the density of events can be compared across regions. It can be argued that point data is the simplest form of symbolised map possible, there is limited ambiguity regarding the location and number of events. Although many other visualisation types exist, should participants struggle to remain oriented within simple geovisualisations, it is likely that participants would experience disorientation within more complex displays.

The aim of the current chapter is to examine whether individuals are able to accurately track their location and the position of data within geovisualisations following passive video tours. In addition, participants' ability to understand information presented within the geovisualisations will be explored. The ability to track position is a key component of maintaining orientation. As discussed previously, spatial orientation can be defined as the *"ability to perceive spatial patterns or to maintain orientation with respect to objects in space"* (Ekstrom, French, Harman & Dermen, 1976, *p*149). When using geovisualisations, users are required to maintain knowledge of the location of objects and data relative to themselves, other items within the geovisualisation and their starting position. Successful use of geovisualisations and accurate interpretation of the presented information is therefore reliant on users' ability to remain oriented. Fundamentally therefore, this chapter seeks to start to apply ideas regarding how individuals remain oriented within symbolised, rather than realistic, spatial environments. Primarily, this chapter will focus on exploring participants' ability to track their position and understand information presented within two geovisualisations, a cluster geovisualisation and a heat map geovisualisation, based on passive video tours. As cluster and heat map geovisualisations can be used to display the same data in different ways, it is possible that participants' ability to track the position of elements within the geovisualisations will differ.

The World Wide Web has become an increasingly important medium for the delivery of information, including entertainment, marketing, social networking and education (Day, Shyi & Wang, 2006). One subset of information which has developed on the web is the display of spatial data (Elzakker, 2001). This data is commonly displayed within web-based interactive maps, also referred to as geovisualisations (MacEachren & Kraak, 2001). It has been estimated that approximately 80% of all data generated contains some form of geographic identifier, including GPS coordinates and addresses (MacEachren & Kraak, 2001). Displaying spatial data in a way that is clear to users and allowing them to maintain knowledge of both their location and the position of elements within geovisualisations is essential if individuals' are to make greatest use of the available information.

Despite the growing importance of geovisualisations, little work has focused on whether individuals are able to remain oriented within these extensive spatial environments (Harrower & Sheesley, 2007). Although geovisualisation tools are potentially rich data display media, human factors in their use are not well understood (Harrower, 2007). Though comparison of different visualisation techniques has occurred (Monmonier, 1996; Krygier & Woods, 2011), Fabrikant (2005) argues that very little is known about the effectiveness of geovisualisations in terms of user benefits, knowledge discovery and usability. As the availability and variety of geovisualisations increases, factors which influence their use should be addressed (Nivala, Brewster & Sarjakoski, 2007, Haklay & Zafiri, 2008). Although research into map use has been completed within both psychology and cartography, there are few examples of collaborative work between these disciplines (Lobben, 2004).

The last decade has seen a considerable increase in the number of geovisualisations, and a corresponding increase in the number of active geovisualisation users (Miller, 2006). Google reports there are over 800,000 uses of the Google Maps API on the web (Marks, 2012), and in February 2012 Google Maps reported over 65 million unique viewers (New York Times 2012, cited in Griffin & Fabrikant, 2012). This rapid expansion of use has been matched by an increase in the tools available for producing geovisualisations, including JavaScript libraries and developer tools, for example editing tools available within the Google maps API (Google, 2012). One feature rarely discussed however is the usability of the visualisations produced with these new tools (Nivala, Sarjakoski, & Sarjakoski, 2007), especially examining this with a population of novice users. This lack of consideration for the user is similar to the lack of usability testing within early GIS systems (Haklay & Zafiri, 2008). Whilst early GIS systems were designed primarily for professional and expert users, geovisualisations are frequently used by novice users, including members of the general public (Miller, 2006). This shift has been described as maps 2.0 (Crampton, 2009). It is possible that novice users may be unable to fully understand their position within the geovisualisation, potentially struggling to make accurate inferences regarding the presented information. If users are not aware of their position, or the position of data within the geovisualisation, they will be unable to accurately interpret the presented information and therefore unable to gain understanding. Lobben (2004) argues that research has traditionally focused on how people read maps rather than questioning the principles and design features of map themselves. In other words, research has been keen to attribute failures of maps to the map reader, rather than the underlying design of the maps.

Geovisualisations build on traditional thematic maps as they are highly interactive environments, which can be viewed and shared online. Geovisualisations have become increasing important as one of the main avenues for the public to interact with spatial data (Keim, 2002). Multiple alternative geovisualisations have been developed. Due to the large quantity of data commonly displayed within geovisualisations however, the problem of data crowding is common. Data crowding (Figure 2.1) occurs when the number of point data symbols on a map rise so that they act to block the view of both additional data points and the underlying map, reducing overall clarity (Krygier & Woods, 2011). Data crowding is a central issue with regards to orientation as the excessive data can act to obscure elements typically used for orientation within the geovisualisation, for example salient landmark cues (Krygier & Woods, 2011). Jenny, Jenny and Raber (2008) propose that within geovisualisations the information density which should be presented to users should be lower than within paper based maps due to the additional demands on digital users, for example as a consequence of navigational demands and technological limitations, including screen resolution. To minimise the effect of data crowding, a variety of different geovisualisation techniques can be used, these rely on amalgamation effects; data is grouped and the available view and presented information changed based on user interaction.

Figure 2.1. An example of a map showing data overcrowding, from transport for London. As can be seen, the number of points indicating bike stations makes it difficult to interpret both the number and location of the bike stations.

Cluster maps (Figure 2.2) address the problem of data crowding by grouping points within a catchment area and replacing the group with a single symbol, usually marked with the number of points it contains. The clustering is recalculated at each zoom step into or out of the map*,* (Mahe & Broadfoot*,* 2010). To illustrate, figure 6.3 displays a zoom within a cluster geovisualisation within Southampton. It can be seen as the user zooms closer into the geovisualisation, the larger clusters break down into smaller clusters and the location of each data point becomes clearer. Cluster markers actively appear, disappear and migrate as the user zooms into or out of the map display (Figure 2.3). The lack of consistent salient landmark cues within the base map may, however, limit a user's ability to remain oriented within the environment (Harrower & Sheesley, 2007), potentially hindering the users' ability to interact with, interpret and use the presented data. As the data is salient there is also the potential for users to use the displayed clusters as landmark cues, as this changes as the user zooms, users may experience disorientation. Should an individual be unable to track either their location or the location of data, they would be unable to gain spatial understanding from the geovisualisation. Despite being used for a variety of governmental open data initiatives, for example the UK crime mapping service available at http://www.police.uk/ limited published work has explored the usability of cluster geovisualisations.

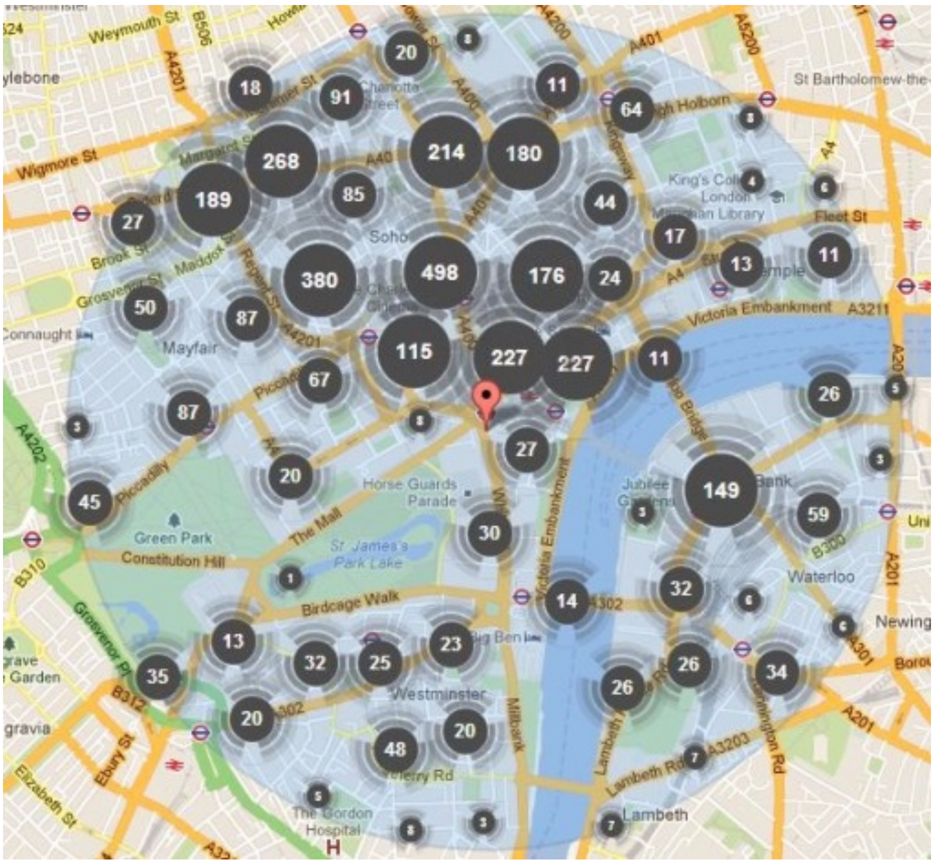


Figure 2.2. An example cluster geovisualisation displaying a large quantity of data. Taken from http://www.police.uk/crime/?q=London,%20UK#crimetypes/2012-09.

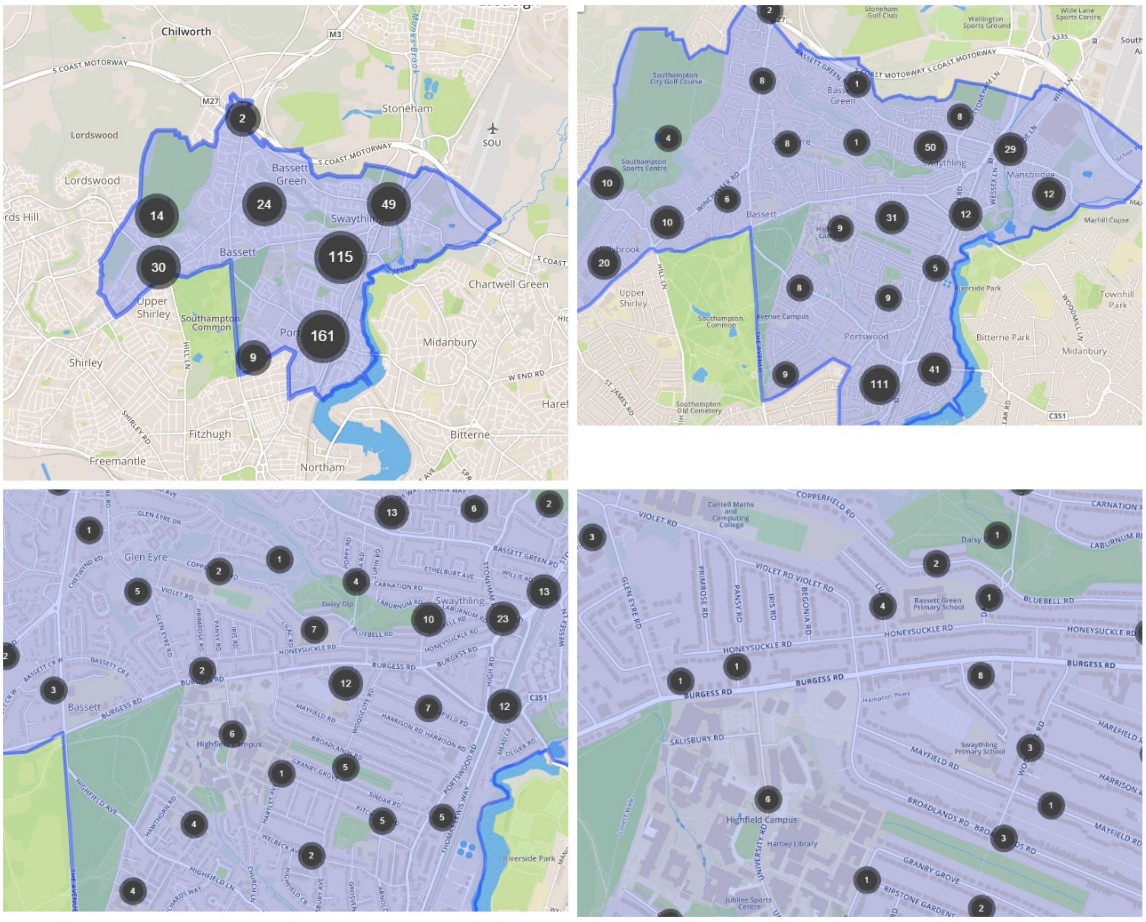


Figure 2.3. An example cluster geovisualisation. At high levels of zoom, there are relatively few, but large clusters present within the geovisualisation. The larger clusters then to separate into multiple smaller clusters. As the zoom in continues, the larger clusters continue to separate to largely be replaced with local markers. At the maximum zoom level all larger clusters have been replaced with street level data. Taken from *http://www.police.uk/hampshire/2SN01/crime/*

Heat maps (Figure 2.4) are density choropleth maps usually using a yellow to red or blue to red 'heat' palette (Harrower & Brewer, 2003). In this type of geovisualisation, instead of clustering in a zoomed out condition individual data points are not visible but rather the density of data is presented. The densities are calculated by a variety of algorithms whose variables can be adjusted by the map designers and are not always apparent to the end user. As a consequence, density plots have received criticism for being easy to bias (Alçada-Almeida, Tralhão, Santos, Coutinho-Rodrigues, 2009; Monmonier, 1996). As categorical divides are rarely apparent to the users and are not common between maps, the map designers can potentially categorise the same data in very different ways depending on the message they wish to convey. This ability to easily manipulate data is potentially damaging to user confidence and level of understanding. However, heat mapping techniques are effective at highlighting differences between locations at the expense of specific detail. That is to say, whilst it is easy to tell if one area has a high density of points compared to another, it is difficult to see the specific number of events associated with either location. Furthermore, without additional keys and legends to the colours it is also not possible for a user to know explicitly how the regions differ. Heat map geovisualisations, like cluster geovisualisations utilise a form of semantic zoom, the symbolisation viewed by the user changes with each zoom step into and out of the geovisualisation. Figure 2.5 illustrate this zoom process within an example heat map. Like the cluster geovisualisation, semantic changes are apparent within the geovisualisation, due to the scale of these changes however, there is greater consistency between the differing zoom layers.

Figure 2.4. Heat map used within Experiment 1. The red shading marks regions of high event density, whist blue shading marks low event density. No events are associated with the unshaded regions.

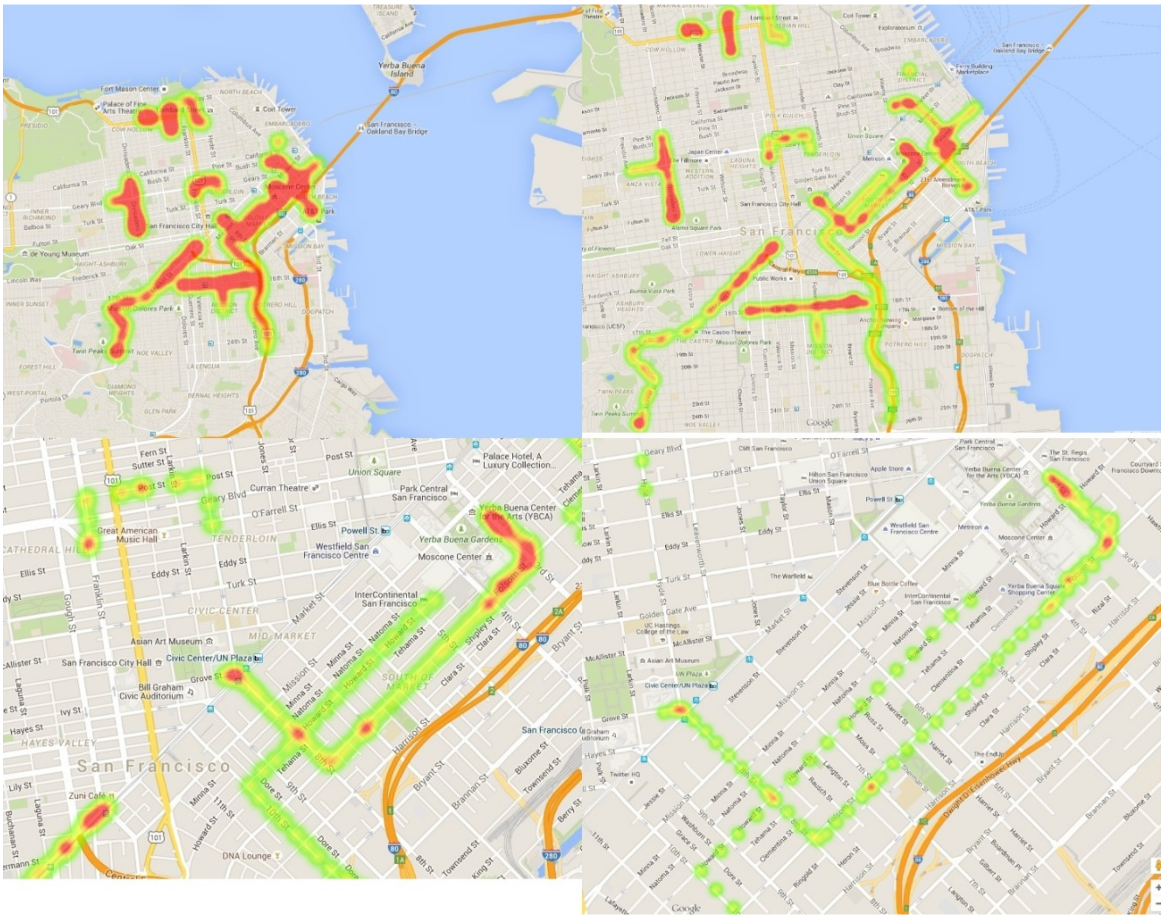


Figure 2.5. An example heat map geovisualisation. The red shading marks regions of high event density, whist yellow and green shading marks low event density. No events are associated with regions with no shading. As the user zooms, the pattern of data becomes more refined and the location of the data becomes clearer. Refinement continues until it is possible to identify the location of individual data points. At the maximum level of zoom, most individual data points are apparent; however regions with greater density retain the red shading. Taken from https://google-developers.appspot.com/maps/documentation/javascript/examples/full/layer-heatmap

Cluster and heat visualisations can be used to display the same data. The data which is displayed can be any which has a geographic identifier, for example the location of a bus stop or a marker for an event, for example a point of crime. Cluster visualisations provide an exact count of a given data source within a given geographical region whereas heat visualisations map the density of a data source within a given geographical region. Although the use of different map types has received attention within cartographic literature, which is better, in terms of effectiveness and ease of use, remains a heavily contested issue. In an extended review of map usability studies, Boscoe and Pickle (2003) suggests that choropleth maps, such as heat maps, were regarded more highly among users and were used accurately due to their simple nature. They note however that cartographers and frequent map users preferred more complex mapping interfaces, due to the increased amount of detail available. Due to differences in the way data is presented, it is likely that users must interact with these displays differently. As a consequence, visualisations may differ in regards to clarity and usability. Jenny et al., (2008) suggest that all maps should be legible at a glance, to allow users to quickly and unambiguously understand the displayed data. Although not producing guidelines for geovisualisations specifically, these guidelines should also be applicable to these displays.

Despite cluster geovisualisations and heat map geovisualisations both being used to display data, it is currently unclear which visualisation is easier for novice users to interact with. This study therefore examined whether participants' ability to maintain orientation and understand the presented information differed between a cluster and heat geovisualisation. Despite theories suggesting that different mapping interfaces may influence users (Harrower & Brewer, 2003; Boscoe & Pickle, 2003), limited attempt to assess these differences has occurred.

To begin to address these questions, a short web based questionnaire was devised. This was kept short, approximately 15 minutes, because of research indicating reduced response rates and increasing drop-out rates as web surveys increased in duration (Marcus, Bosnjak, Lindner, Pilischenko & Schuetz, 2007; Galesic & Bosnjak, 2009). For the current study questionnaire, participants were required to complete two geovisualisation based tasks, whereby they would witness pre-recorded video tours of interactions within either a heat or cluster map, before being asked a series of questions regarding the layout of the data within the display. The tours consisted of zooming in, out of and panning within the geovisualisation. Following each tour, participants were required to offer feedback on the geovisualisations and suggest potential ways to improve them.

From the research available, several key hypotheses can be developed

1) Participants will struggle to maintain a sense of location within the geovisualisations, as demonstrated by an inability to accurately track the location of key events (Midtbø & Nordvik, 2007).
2) Participants will rate the heat map geovisualisation as more usable than the cluster geovisualisation (Lewandowsky et al., 1993, cited in Boscoe & Pickle, 2003; Boscoe & Pickle, 2003)
3) Participants' qualitative opinions of the two geovisualisations will be different due to the way data is presented (Monmonier, 1996).

Method

Design

The study was a web-based questionnaire. The questionnaire took approximately 15 minutes to complete and is available at https://www.isurvey.soton.ac.uk/condition_start.php?id=145. The order that the maps were presented to participants was counterbalanced, as was the location of the maps.

Participants and Recruitment

Participants were 394 respondents (303 Females, 88 Males and 3 Undisclosed), aged 16 – 72 Years (Mean = 22.46 years, Standard Deviation = 7.69 years, 7 participants did not disclose their age). The study was advertised via the use of social media, including Twitter and Facebook and a variety of online fora. An online advert was also placed on an internal intranet and posters were disseminated across The University of Southampton's Highfield campus. Participants were not offered compensation for time spent completing this study.

Apparatus

The primary apparatus used within this study were the video tours of the geovisualisations which participants observed as part of this study. Participants were presented with a series of video showing geovisualisations displaying the location of fictitious crime data being zoomed and panned. The geovisualisations were based on tools available within the Google maps API, as such both used a Google Maps base layer map, and only the nature of the data layer differed between visualisations. Participants were shown videos of both the cluster and heat map sequentially, although order was randomised. Videos were made so that the time spent in each part of the tour for each geovisualisation and map type was as identical as possible to ensure that the videos themselves did not act as a confounding variable.

Each video zoomed into one corner of a clearly marked region of interest within the geovisualisation, zooming back out to a high view, before zooming again into the opposite corner. This ‘tour’ ensured that users experienced the dynamic symbol changes apparent within both types of visualisation due to the use of semantic zoom. An example video used within this study is available at http://www.youtube.com/watch?v=-ufnzeAsTvU, which shows a cluster geovisualisation, based within the city of Minsk.

The geovisualisations were placed over cities in Eastern Europe in an attempt to minimise the likelihood that participants were familiar with these locations. Pilot investigations suggested that familiarity influenced participants’ subsequent opinions of data, although this is an interesting finding and warrants attention, it was not the focus of this study and had the potential to act as a confounding variable. As a consequence, participants who indicated high familiarity with the regions used within the study were removed from the final analysis ($n = 2$). Furthermore, the displayed data was fictional and created for the purpose of the study. This was to ensure the number of data points within each map geovisualisation was the same, and not dependent on the locations chosen. Participants were not however informed that the data was fictional until the study had been completed. Participants examined the alternative map types (Cluster/ Heat) within different cities to ensure that participants did not examine the same data within two different map types. Map type and city were counterbalanced to minimise potential order and location effects due to a particular map type or city. Both maps types and location displayed the same number of individual data points (100), however the pattern created by the data was different in both locations.

Procedure

The procedure used within this study was primarily based upon Midtbø and Nordvik (2007) who used a web based interaction task and survey to investigate the impact of zoom on participants' ability to track the location of a hidden beacon within a series of map interaction videos.

A web based survey was chosen for this study in order to investigate as large and diverse user population as possible. After participants had followed a link to the questionnaire, but prior to participating within the research study, they were presented with a digitised information sheet which explained the aims of the study, what participants would see if they agreed to participate and explained participants' ethical rights. Participants were required to indicate that they had read the information sheet and consent to participate in the study before they could proceed. The main questionnaire contained two key elements, a demographics section, collecting basic information regarding the respondents, for example age and gender, and the primary geovisualisation tasks. The aim of the geovisualisation tasks was to obtain qualitative data regarding users' opinions about the geovisualisations, for example whether the maps were easy to understand, whether the presented information was clear; and data about their performance using the geovisualisations to solve typical problems, for example tracking where the highest density of data points were located. This task was chosen as in order to track the position of highest density of data within the geovisualisation users must maintain knowledge of the displayed data and understand relative position within the display, analogous to an orientation task.

Prior to the start of data collection, 20 iterative pilot studies were run to ensure that the questionnaire was functional and clear to participants. During pilot testing the wording of several questions were rephrased so that they were clearer, and questions which were deemed as unneeded or confusing for participants were removed from the study. Data gathered as part of the pilot investigation was not included in the final analysis.

Results

Data Analysis

All questionnaire data was automatically stored within a web survey application ‘isurvey.soton.ac.uk’. This service was developed by, and is hosted within the University of Southampton. The use of an internal survey tool allowed the researchers to have greater control of who has access to the data and to better ensure participant confidentiality.

Participants’ responses were collated across counterbalance groupings. Participants’ understanding of the map displays was based primarily on their ability to correctly identify the densest area of crime within the visualisations. In order to achieve this, the map was divided into a 3 x 3 grid, and participants’ responses compared to the densest crime region within each location. Participants were judged as providing a correct response if their response matched the region with the greatest density of crime data. If participants indicated any other region they were judged as giving being incorrect. This approach was necessary based on participants’ responses, as participants were often vague or would give responses relating to the cardinal region of the map. Content analysis (Holsti, 1969) was used when examining collected qualitative data to describe trends within participants’ comments.

Results clearly indicate that a considerable number of users were unable to accurately interpret the data within either the cluster or heat display. Accuracy across geovisualisation type and location is presented in figure 2.6. Although accuracy for both geovisualisation types was considerably lower than anticipated, participants were more accurate when interacting with the heat map geovisualisations than the cluster geovisualisations.

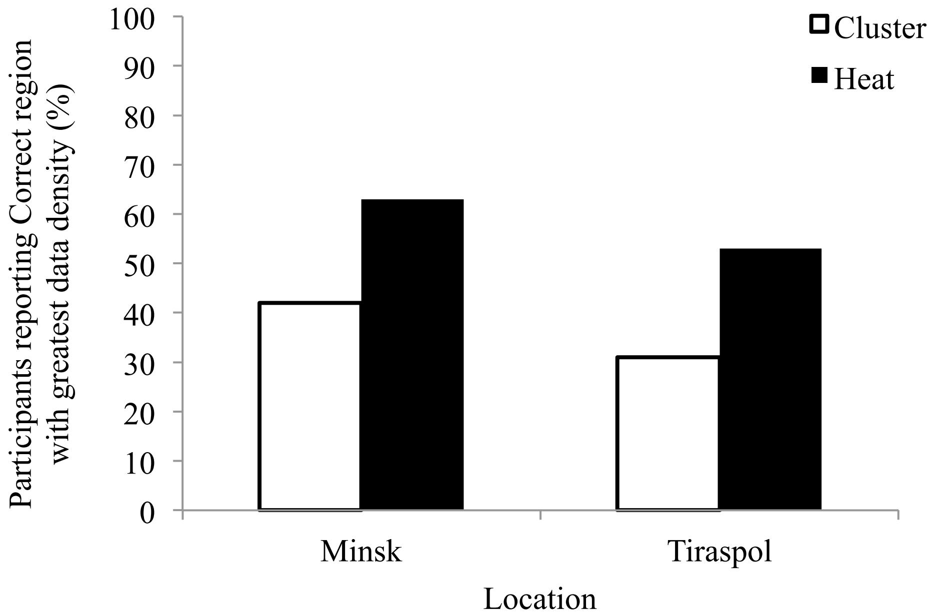


Figure 2.6. Participants recorded accuracy at identifying and tracking region of greatest data density within the display, for both geovisualisation types and locations. It can be seen that participants were more accurate when using the heat opposed to the cluster geovisualisations.

These results are indicative that many participants struggled to accurately track the position of data within the geovisualisations during the tours. Should users have been able to accurately interpret the presented information and accurately track their movements within the geovisualisations, a higher degree of accuracy would have been expected within both geovisualisations. Although participants were more accurate using the heat map, they appeared to generally struggle to accurately track the region of greatest data density within both geovisualisations. This suggests that participants were not able to remain orientated, maintain a sense of the location and the position of items (the data) within the geovisualisations as the tours zoomed and panned.

The trend for greater accuracy within the heat maps continues when participants were asked to describe the visualisations and explain how the geovisualisation displayed data. It was found that users were frequently able to better explain what the heat map visualisation represented:

"Crime density in a specific area is represented as shades of colour ranging from blue to orange/red. The more intense the orange/red the colour the higher the crime density in the area"

This is not to say that all participants were able to accurately interpret the heat map however. Many participants made considerable errors. One error included confusing density of crime events with the recorded severity of crime.

"Red areas: particularly extreme crime, blue outline crime dissipates to less serious crime (e.g. shop lifting as opposed to knife crime)"

This finding indicates that despite the apparent simplicity of heat map, many participants still require guidance to be able to accurately interpret the presented information. Although errors such the above example can be seen as substantial, these errors were within the minority. Fundamentally however it was clear from recorded responses that the principles of the heat map were generally well understood by the majority of participants.

In comparison, participants' demonstrated a far weaker understanding of the cluster maps visualisations. Although the majority of participants were able to offer a basic explanation of what a cluster map shows, they seldom provided sufficient detail to illustrate clear understanding. An example comment illustrating this:

"Balloons indicate individual crime, circles show multiple crime that occurred close to one another"

Issues relating to amalgamation of the different crime markers into larger clusters were rarely mentioned, suggesting that participants did not fully understand this process, or the implications of semantic zoom on the location of individual data points. The nature of the visualisation, whereby each point is clearly presented as a numerical value, and that this study was completed as a short web based questionnaire may, however, have encouraged participants to offer superficial descriptions of the display. Participants' low level of accuracy using this visualisation however, suggests that participants did lack a fundamental understanding of the geovisualisation.

In order to compare which geovisualisation participants preferred, preference was addressed as a closed question once participants had interacted with both geovisualisation types. Figure 2.7 displays the responses to this question. From this figure it would appear that, despite evidence that many users were unable to accurately interpret the cluster maps, the majority of participants preferred this visualisation. This suggests that participants are not aware of the mistakes they are making when interpreting this geovisualisation type.

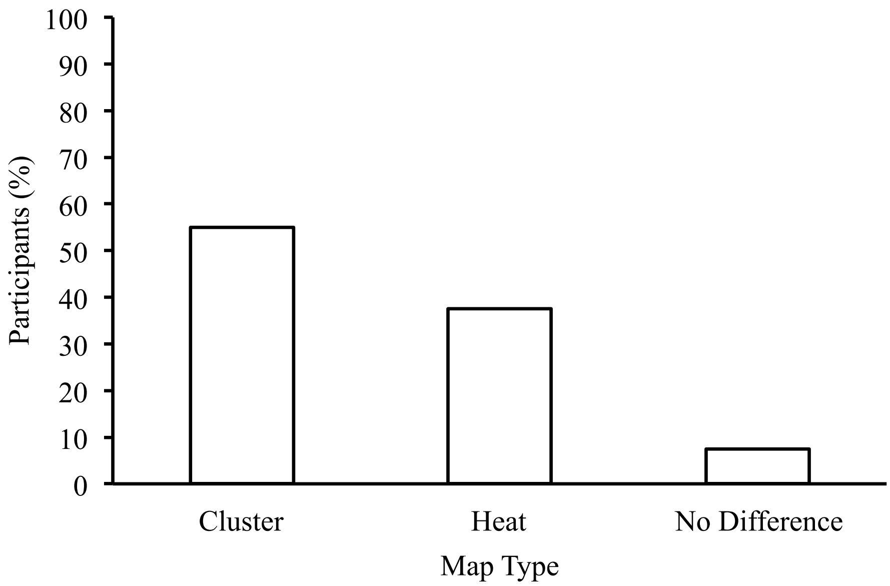


Figure 2.7. Participants preferred geovisualisation. Despite participants recording lower accuracy within the cluster geovisualisation, it is apparent that the majority of participants preferred this display.

Participants were asked within a follow up question to explain why they preferred the geovisualisation which they did. The most common reasoning for the cluster geovisualisation related to the inclusion of numerical values within this display. An example quote about this topic:

"Because there was a number it was easier to comprehend the actual number of crime"

Participants who preferred cluster geovisualisations argued that because of the inclusion of numerical symbols, the displayed data was specific, unambiguous and easy to interpret. The heat map in contrast did not offer a clear indication to participants regarding the exact number of crime events within the region, rather it focussed on the relative density and distribution of crime. These comments can be seen as further evidence that participants were not fully aware of the mistakes they were making in interpreting this display. Participants who indicated a preference for the heat map suggested that the cluster geovisualisation was unreliable due to amalgamation effects and that the semantic zoom made it difficult to understand the location of individual crime events. This suggests that although semantic zoom may act to reduce data density within a geovisualisation, it can also directly impact users' confidence and understanding. It should be noted that the heat map also utilises semantic zoom, albeit more subtly. It appears therefore that participants viewed the less dramatic changes within the heat map as less disruptive to their overall experience.

One finding that should not be ignored is the number of participants who directly commented that they did not understand the symbolisation used within the geovisualisations. Such participants either did not understand the working of the cluster geovisualisation, due to the changing data points, or the heat map due to a lack of details regarding the meaning of the colour distribution. Although participants voicing these opinions were in the minority, (n = 24, 6.09%), it is clear that further assistance is needed to ensure all participants are able to interpret the basic information they are presented with. Although a comparatively small proportion of participants openly voiced that they did not understand the geovisualisations, the results of the test suggest that a considerably greater number of participants struggled with interpreting the symbolisation within the geovisualisations. In addition to a failure to remain adequately oriented, participants' poor performance within the accuracy trials may be related to a lack of understanding of the symbolisation within the displays.

"The symbols were not at all clear"

"I don't have a clue."

"Not sure... Doesn't seem to work like a regular heat map as the blobs change when you zoom in!"

Overall results from this study suggest that participants struggled to accurately track changes within the map display, as demonstrated by their inability to accurately recall the region with highest data density. It was clear that neither geovisualisation type was definitively preferred to the other, although a marginal number of participants preferred the cluster visualisation, 55% of participants compared to 37.5% of participants who preferred the heat map geovisualisation, primarily due to the presence of numerical values. The cluster geovisualisation recorded lower accuracy, as demonstrated by participants being unable to identify the region of greatest data density. Finally, it was noted that several participants were unable to interpret the information within the geovisualisation due to not understanding the symbolisation used.

Discussion

Results from the current study indicate that neither geovisualisation type was well understood by users. Heat map geovisualisations were however interpreted marginally more accurately than the cluster geovisualisations. Participants' inability to track the region with the greatest data density is indicative that participants were unable to track their changing position and the position of the data within the geovisualisations. In addition it was found that despite more participants indicating a preference for the cluster geovisualisation, participants were unable accurately use and interpret this display, as demonstrated by an inability to track the region with the highest data density.

Of key interest to the current research is the finding that participants were unable to track the region of highest data density with the maps after watching the video tours. This finding is highly similar to that shown by Midtbø and Nordvik (2007), who showed that participants struggled to accurately track the location of a marker during a recorded tour within a semantic zoom interactive map. The added presence of data within the geovisualisations does not appear to aid participants in tracking their position. Although both geovisualisations within the current study use semantic zoom, it can be proposed that there are less abrupt changes to the overall symbolisation within the heat map which lead to participants increased accuracy when using this geovisualisation. When examining changes within the cluster geovisualisation, the breakdown of the clusters into multiple smaller clusters means that there are few consistencies between differing data layers visible at different zoom levels. In contrast, the changes seen within the heat map geovisualisation can be seen as series of refinements, with each point becoming clearer as the users zooms. Due to greater visual consistency between the differing data layers, participants' are more able to track their position and interpret the presented information. However, results suggest that for both geovisualisations the inclusion of data within the display does not help participants to remain oriented within geovisualisations. Rather it appears that the added data leads to greater complexity in participants' task. Participants are required to understand both the symbolisation within the display and to track their movement and data changes within the display, a task participants struggled to achieve.

The finding that participants were more accurate using the heat map matches the results of Lewandowsky et al. (1993). They found that choropleth maps were more accurately used than alternative geovisualisations including dot maps. Whilst heat map geovisualisations are not strictly choropleth maps, both use colour shading to represent data within a geographical region, and can be seen as the spatial equivalent of histograms (Haklay, 2010). This is in contrast to the cluster geovisualisation which directly presents numerical data. Within the current study it was found that participants were more accurate using the heat map, both in terms of accuracy when identifying and tracking the region of highest crime density and also in terms of offering greater detail when explaining how the symbolisation worked. As an explanation regarding the symbolisation was not offered to participants this suggests that the heat map was more intuitive to participants. This finding can be contrasted however with information regarding participants' preference. The finding that participants preferred the cluster geovisualisation was not anticipated based on previous research (Boscoe & Pickle, 2003; Lewandowsky et al., 1993). Results from Boscoe and Pickle (2003) suggest that the heat map geovisualisation would be rated more highly due to the simplicity of the symbolisation. Furthermore, it was found that despite many participants suggesting that the cluster geovisualisation was clearer, participants were not accurate using this geovisualisation. It could be suggested that the cluster geovisualisations appear to be simpler than they actually are. Due to the visible numerical values, participants are not aware of the relationship between the data layers and base map within the geovisualisation. Due to the semantic nature of the display, participants are unable to accurately track the position of the data, as it zooms and thus make large errors when interpreting the visualisation. This indicates that users require additional guidance to understand the link between these different aspects of the geovisualisation.

Overall, it was found that participants were inaccurate using both geovisualisations. It could be argued that participants' requirement to watch a passive tour of the environment rather than interact with the geovisualisation themselves may have impacted accuracy.

Previous research has indicated however that despite interactive environments being more highly rated than animated and static environments little differences is apparent in terms of learning outcomes (Yeung, Schmid, George & King, 2012). Numerous researchers have however stressed that interactivity can increase participants motivation to use digital environments (Mabrito, 2004) which in turn can result in positive learning outcomes. Croxton (2014) argues that greater interactivity assists in users persisting with using a system and promotes engagement from the users. In addition, numerous studies have been developed to promote interactive engagement with online courses and learning tools (Song & Yuan, 2014) due to a view that interactivity would benefit the user. It would be beneficial therefore to explore this effect further to examine whether the opportunity to interact with the geovisualisations benefits users understanding and ability to remain oriented.

Conclusion

Results from this study suggest that many participants were not accurate when interpreting either geovisualisation type. This result was demonstrated by participants' inability to track the region with the greatest density of data. This suggests that participants were unable to track the position of the data within the geovisualisations, potential evidence that they are becoming disoriented, supporting hypothesis 1. Furthermore, it was seen within participants' responses that despite recording lower accuracy when interpreting the cluster display, participants preferred this geovisualisation. This suggests that participants are not aware of mistakes they are making when using this display. This finding was not anticipated based on previous research and was counter to hypothesis 2. Participants qualitative comments regarding the geovisualisations did differ, participants expressed greater understanding of the heat map geovisualisation than the cluster geovisualisation. Although supporting hypothesis 3, participants rarely offered substantive detail when discussing the geovisualisations, further work within a more controlled setting is therefore needed to examine this further. Future work is also needed to examine whether interactivity will benefit participants ability to understand the symbolisation used and adequately track the data within the geovisualisations.

Chapter 3

Experiment 2 - The Influence of interactivity on maintaining orientation within Geovisualisations

Results from Experiment 1 indicated that participants struggled to accurately track the location of the greatest density of points within the presented geovisualisations. One factor, which was not considered within this study, was the role of interactivity. Interactivity has been demonstrated to be a key component of participants' ability to remain oriented and track position within a variety of virtual environments (Hegarty, 2004; Keehner, Hegarty, Cohen, Khooshabeh & Montello 2008). Interactivity has also been viewed as an essential component of modern geovisualisations, MacEachren and Kraak (2001) argue that *"Today's cartographic environments are characterized by two key words: Interaction and Dynamics"* (*p*3). Kraak and Brown (2003) suggested that the shift to the use of computerised tools, including GIS has enabled the user not only to interact with visualisations in a spatial context, but also explore the data behind them. Lloyd, Dykes and Radburn (2007) argue that successful use of geovisualisations should be considered as a process, whereby users explore ideas and discover information about the environment. In order to complete this process, users must be able to interact with the geovisualisation, and be in control of their movement.

It can be argued that the methodology employed within Experiment 1 may be lacking ecological validity. Geovisualisations encountered commonly rely on user exploration and interaction rather than a pre-recorded tour. Previous investigations do, however, show mixed results regarding the value of interactivity. Although there is considerable evidence that interactivity is of benefit to users when exploring virtual environments (Peruch, Vercher & Gauthier, 1995), the concept is considerably less clear when it comes to the use of interactive data and visualisations. Krygier, Reeves, Cupp and DiBiase (1997) suggest a taxonomy of interaction types available to visualisations, based on the interactivity and level of control users have within the system, ranging from static, whereby no interaction exists, to conditional, a system where the user has full control over action within the system. Each level of interactivity within the taxonomy has associated strengths and weaknesses due to an inherent conflict between ease of use and potential level of detail which can be provided. As interactivity increases, so does the complexity of use. Betrancourt (2005) in contrast offers a dichotomous divide between low level interactions, such as playing and pausing a presentation (their term for a tour) to high level interactions whereby users actively engage with a system, for example having the ability to change viewpoint. Keehner et al. (2008) argues that whether interactivity is positive cannot be considered a simple yes or no response but rather is dependent on the task at hand and the characteristics of the users. It has been argued (Keehner, et al., 2008; Hegarty & Waller, 2004) that a key factor is not the nature of interactivity per se, but rather whether users are aware how to best utilise the available interactivity to accomplish the task at hand. Keehner et al. emphasises that it is not just a matter of whether individuals can interact with a system or visualisation, but rather, how they interact with such a system. They note that detailed examinations of users' behaviours are largely lacking within the literature. The current experiment aims to begin to partially address this lack of study, by examining how users interact with a series of different geovisualisations. By providing participants with an interactive geovisualisation, it will be possible to see whether the orientation difficulties identified in Experiment 1 were a consequence of the lack of interactivity and control or whether they are more fundamental within the use of geovisualisations.

As discussed previously (See Chapters 1 and 2), users must also understand the symbolisation used to represent data within geovisualisations. The current study explores a choropleth grid map and cluster visualisation. The relative strength and weaknesses of both these visualisations types have already been discussed previously and as such will not be repeated here. Evidence from Experiment 1 indicates, however, that when participants watched passive tours of geovisualisation, they struggled to remain oriented and accurately interpret data within both cluster and heat geovisualisations. With increased interactivity, and therefore potentially more time to examine the geovisualisation, users may develop a better understanding of the distribution and the meaning of the presented data. Whether this is the case, or whether greater intervention to boost participants understanding of the symbolisation is required is currently unclear.

The current study explores participants' ability to understand a geovisualisation, either a cluster map or a choropleth grid map. Specifically, this study examines the extent to which participants are able to use the information presented within the geovisualisation to make a series of judgements, identifying regions of high and low data density within the layers visible at different zoom levels of the geovisualisations. This study expands on Experiment 1 by exploring the role of interactivity within the use of geovisualisations. This study also examines difficulties that participants encounter when exploring geovisualisations in attempt to establish common problems that should be addressed.

This study does make use of Google Earth rather than Google Maps, which would have been the preferred medium for this study. Google Earth offers far greater interactive controls than Google Maps, including the ability to tilt and rotate the display in addition to pan and zoom. Previous research has however indicated that participants under task conditions and time pressure whilst using Google Earth do not utilise tilt and rotate functionality (Wilkening & Fabrikant, 2013), and rather maintain use of pan and zoom.

Such a finding has also been recorded when participants are not under time pressure, but required to complete tasks using interactive visualisation tools (Keehner et al., 2008). As a consequence, although not ideal, this compromise is deemed appropriate.

Based on the findings from Experiment 1, and previous literature the following hypotheses can be proposed:-

1. Participants will record reduced latency when using the choropleth grid geovisualisation compared to the cluster geovisualisation (Boscoe & Pickle, 2003)

2. Participants will be more accurate using choropleth grid geovisualisation than the cluster geovisualisation (Boscoe & Pickle, 2003; Experiment 1).

Method

Design

This study used an independent, between subject design. Participants were randomly allocated between four conditions, Camden Cluster, Camden Grid, Mayfair Cluster and Mayfair Grid. The independent variables were geovisualisation type (Cluster/ Choropleth) and location (Camden/ Mayfair). The dependent variables were the time that participants required to complete each of the map based tasks, and the accuracy with which these tasks were completed.

Participants

Participants were 120 psychology undergraduate students, from the University of Southampton, who completed the study in partial fulfilment of a research participation scheme. Participants were recruited via the use of a departmental recruiting system. 99

participants were female (82.5%) and 21 were male (17.5%). 88 participants identified themselves as British (73.3%). Age demographics were not collected. 116 participants (96.7%) had used Google Earth previously; however usage revolved around navigation and landscape exploration.

Apparatus

The study took place within the same research cubical as used previously. The cubicle contained one desktop computer. The computer used a standard Windows 7 operating system, connected to a keyboard and mouse, placed on a desk in the centre of the rear wall. The computer was connected to three 15” LCD monitors, each displaying an independent aspect of the study. The left most monitor displayed a demographics questionnaire, the centre monitor a map based interaction task, and the right most monitor, a reflective questionnaire. The computer had sufficient graphic acceleration and broadband connection to fluidly run Google Earth (Freely available). A disadvantage of using Google Earth to simulate the interaction with the geovisualisations is increased navigational freedom beyond that available within Google Maps. Due to this freedom, it is possible for participants to explore the wider environment rather than being constrained to the area of interest. As stated previously however, studies investigating the use of virtual globe software have found that participants focus on the task at hand and do not utilise extra freedoms and controls that may be available, including tilt and rotate controls. From the perspective of the study creation, data layers can be added to Google Earth via the use of Keyhole Markup Language (KML). KML is machine readable code which allows the annotation of maps and virtual earth software tools, including Google Earth. In this experiment, the regions functionality of KML was used to produce semantic zoom.

Regions comprised of three images that altered as users interacted which acted as the data layers of the geovisualisations. Active regions varied depending on condition. The images displayed either a cluster map (Group Cluster) (Figure 3.1), or a choropleth grid map (Group Grid) (Figure 3.2), covering an area of London, Camden or Mayfair. At high and medium altitude, participants saw the group dependent geovisualisation. All cluster maps were taken directly from Police.uk, the official UK crime mapping website, and imported into Google Earth. Due to the implementation of semantic zoom, the visible clusters dispersed between zoom levels. For the choropleth grid geovisualisations, a series of 100 coloured square polygons were created and layered over the corresponding area. Each polygon was given a colour fill based on the density of crime at the location, using the same data available from police.uk. As the presented information within the choropleth grid maps directly represented the same information as presented within the cluster maps, the dispersal of the clusters within the cluster maps meant that several squares within the grid map changed category. Both visualisation types displayed the same information, allowing for a direct comparison and controlling for potential variation within the data which may have otherwise acted as a confounding variable. As participants within both conditions continued to zoom, the medium altitude data layer faded to street level crime markers. The street layer, which displayed crime per street, was the same for both conditions. At street level, roads which had crime associated with them were marked by a point containing the number of crimes which had occurred in that street, similar to the high and medium altitude zoom seen by Group Cluster, albeit far more detailed. If no crimes were associated with the street no marker was shown (Figure 3.3). A translucent grid and coordinate reference system was placed onto and next to the map display respectively. These additions allowed for clear instructions to be presented to participants, whilst also potentially constraining their overall navigation to the area of interest. Participant interactions with the maps were recorded using an installed screen reader (BB Flashback, freely available) that was not visible to the participants during the study and did not influence the system in anyway.

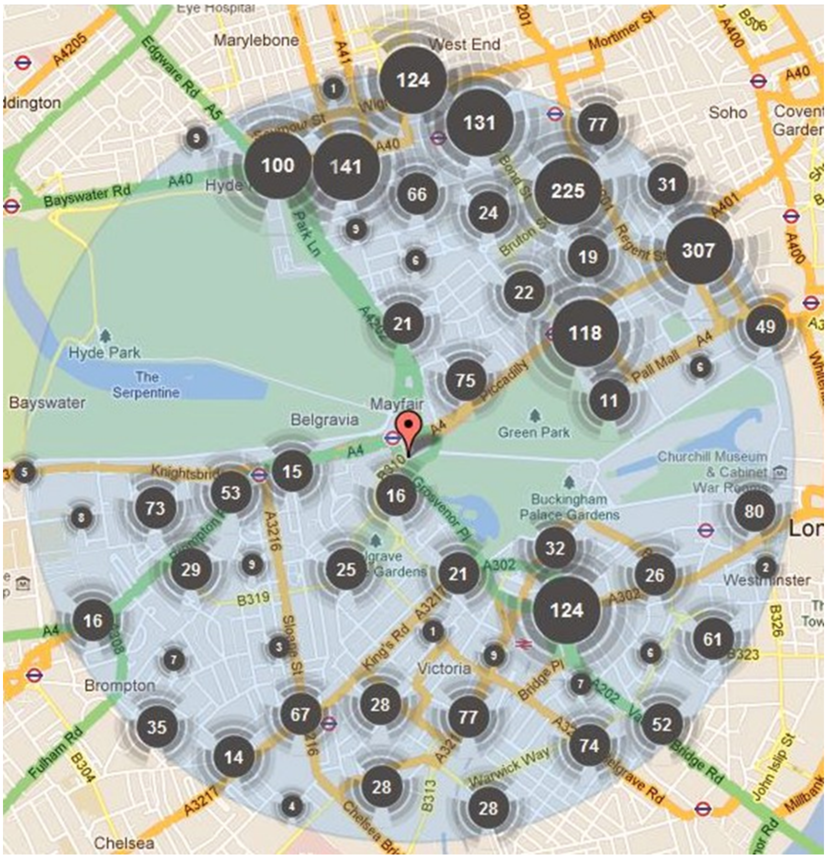


Figure 3.1. Cluster Map displaying crime within Mayfair. This was used as the initial visualisations for participants within Group Cluster, Mayfair.

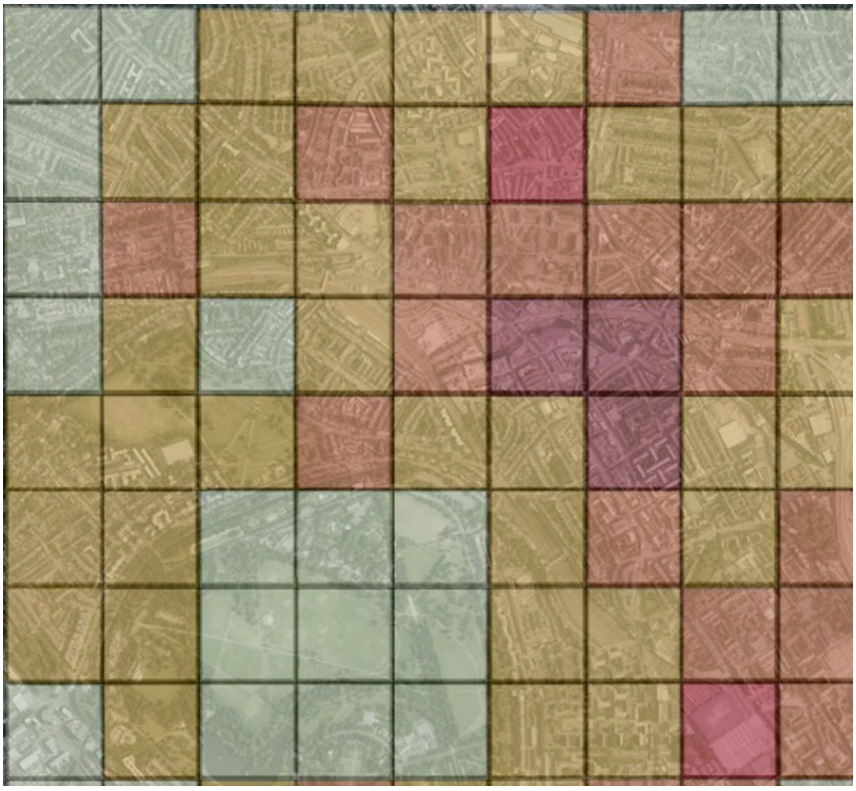


Figure 3.2. Choropleth grid Map displaying crime density within Camden. This was used as one of the initial visualisations for participants within Group Grid, Camden.

Figure 3.3. A zoomed view of the Camden high crime density region. This was seen by participants who interacted with the Camden visualisations, from both conditions. The number of crimes associated with each road is displayed as a circled number placed approximately in the centre of the road.

Measures

Participants were required to complete two questionnaires as part of the study. The initial questionnaire focused on participant demographics and their use of digital maps, including Google Maps and Google Earth. Specifically, participants were asked how often they had interacted with these services, whether they found them easy to use, and the purpose of previous interactions. A second, reflective questionnaire, completed after the visualisation interaction component of the study, focused on the usability of the display, including ease of use and clarity. The reflective questionnaire examined participants' use of and opinion of the geovisualisation that they had been presented within a series of open questions.

Procedure

Participants were invited to complete a study investigating their ability to use web-based maps. Prior to start of the study, participants were presented with an information sheet outlining the aims of the research and participants' ethical rights. Participants were required to give written consent before participating. Participants completed the study with no outside assistance. The experimenter informed participants of the requirements of the study, how to use the questionnaire tools, how to use Google Earth, and answered any questions the participants had regarding the study or the materials being presented during the investigation. The experimenter however left the research cubicle at the start of the study to ensure that their presence would not influence responses. The participants completed all aspects of the study once the experimenter left. The study took approximately 25 minutes to complete.

Participants completed the demographic questionnaire before interacting with one of the geovisualisations (Cluster / Grid). Tasks within the geovisualisations were divided between basic competency tasks and exploration tasks (see Table 3.1.). Basic competency tasks focused on participants' ability to use the geovisualisation to examine overall trends, for example "Where within the display has the highest Crime rate?". These tasks were used to ensure that the all participants had experience interpreting the geovisualisation displays and to compare the initial usability of the cluster and choropleth grid geovisualisations. These tasks did not require the user to zoom within the display and therefore directly examined whether participants understood the symbolisation, prior to being required to explore and orient. Exploration tasks required participants to zoom to a given region of the geovisualisation and answer a specific question relating to the streets within the square, for example “Square J4 is a convenient area. Where is the lowest crime, as regards streets within this square?”. The target of the search was either consistent or inconsistent with the overall rating of the area. This was to explore whether the manipulation of zooming interfered with knowledge gained from the top layer of the map. Participants completed two consistent searches and two inconsistent searches. For consistent searches participants looked for a high crime street within a high crime area and searched for a low crime street within a low crime area. Within inconsistent tasks participants were required to search for a low crime street within a high crime area and for a high crime street within a low crime area. Tasks were presented as a short fictional scenario of relocating to a given area within London, with the visualisations being used to judge the safest area to relocate to. All tasks were presented via a short paper booklet, though all participant interactions were required to be within the map interface, answers being given by a mouse click. No feedback regarding accuracy of responses was given to participants. Exploration tasks required participants to zoom and pan within the environment and therefore track their position within the display, introducing a requirement to orient. The order the geovisualisation tasks were completed was counterbalanced, however all participants completed the basic competency tasks prior to completing the exploration tasks.

Table 3.1. Task Breakdown for the Map Interaction Tasks

Task Category	Trial	Consistency	Task outline
Basic Competency			
	T1		Locate area of Highest Crime in the map
	T2		Locate area of Lowest Crime in the map
Exploration			
	T3	Consistent	Locate Highest Crime in a High Crime Region
	T4	Consistent	Locate Lowest Crime in a Low Crime Region
	T5	Inconsistent	Locate Lowest Crime in a High Crime Region
	T6	Inconsistent	Locate Highest Crime in a Low Crime Region

Note. Counterbalancing switched the order of T1 with T2, T3 with T4, T5 with T6.

Once participants had completed all geovisualisation tasks, they were required to complete the reflective questionnaire. Once participants had completed this questionnaire, they left the cubical and were presented with a debriefing form. The experimenter also answered any questions which the participant may have had regarding the study.

Results

Data Analysis

Analysis comprised of two main elements; participant screen recordings and participant questionnaire responses. Participant screen recordings were examined and the time participants took to complete each task was recorded. Participants' answers were reviewed and compared to the optimal response. To ensure the accuracy of the recorded timing, the recordings of eight participants were examined twice at different stages of analysis by the experimenter to ensure that the recorded timings were consistent. No differences were observed between the recorded timings. It would have been preferable to have these recordings check by a secondary party, however this was not possible within the time constraints of the current study. It should be noted that participants were instructed to move their mouse pointer away from the visualisation between each question to ensure a clear timing point, however very few participants completed this step. To counter this, timing began from when participants first moved their mouse after indicating their previous response. Although participants would have been able to see some of the maps at times which their mouse was still, this timing approach does enable the researchers to examine latency relatively accurately for the exploration tasks, as participants were required to zoom between layers and travel to set locations in order to answer the questions being posed. Timings and accuracy were compared across conditions.

Final analysis involved the use of content analysis (Holsti, 1969) regarding participants open responses within the reflective questionnaire. Grounded approach (Glaser & Strauss, 1967) was used, with themes emerging based on participants' remarks. A coding metric was developed, which focused on key emergent themes.

The alpha level for all comparisons was set at .05.

Participants' latency and accuracy were calculated and groups compared. Results from participants' recordings are divided into three main components; I) latency when completing basic competency tasks, II) latency for the exploration trials, focusing on the difference between consistent and inconsistent trials, and III) accuracy of responses during the exploration trials. This is supported by content analysis of qualitative data responses of the difficulties which participants experienced using the geovisualisations identified within the reflective questionnaire.

For the basic competency tasks, participants were required to search for areas of general high crime (low crime within counterbalance) before identifying areas of general low crime (high crime within the counterbalance condition). As all bar one participant within Group Cluster were able to accurately identify correct areas within the display, only the latency of these trials were compared across conditions. Mean time required by participants is presented in Figure 3.4. Participants using cluster geovisualisations took longer (M= 60.10, SD= 62.06) than participants using the choropleth grid geovisualisation (M= 47.45, SD= 48.85) during the first competency trial. This difference was however reversed within the second trial with participants using the cluster geovisualisations becoming faster (M= 33.81, SD= 24.62) than participants using the choropleth grid geovisualisations (*M*= 55.35, *SD*= 55.22). This suggests that although participants struggled to use the cluster geovisualisation when first presented, they became faster with repeated trials. In contrast, Group Grids latency did not improve over the two trials.

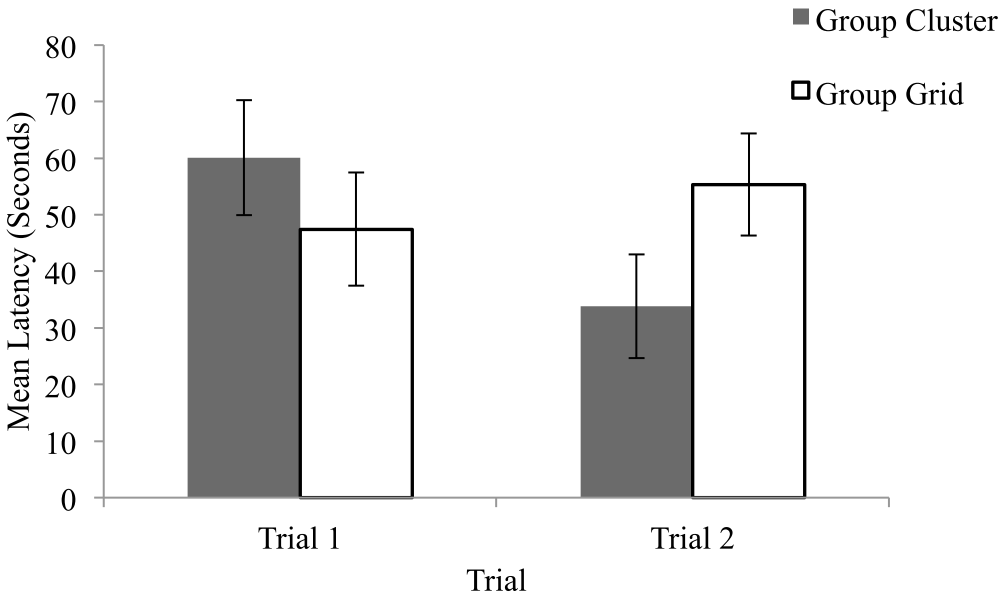


Figure 3.4. Participants mean latency when completing the basic competency trials, by condition. Group Cluster mean latency was significantly reduced within the second trial. Group Grid mean latency however does not significantly differ between the two trials. Error bars represent the estimated standard error of the mean.

To explore these timings in greater detail, a 2 Trial (Trial 1, Trial 2) X 2 Map Type (Cluster/ Grid) X 2 Location (Camden/ Mayfair) X 2 Counterbalance (Counterbalance 1, Counterbalance 2) mixed design analysis of variance (ANOVA) was conducted on participants' time to complete the basic competency tasks. The main effect of trial was not significant, $F(1, 111) = 3.28$, *ns,* $\eta_p^2 = .03$. Additionally no main effect of counterbalance group was seen, $F(1, 111) = 2.89$, *ns,* $\eta_p^2 = .03$. Furthermore, no main effects of map type *F*<1, *ns,* η_p^2 = .001, or location were observed, *F*s<1, *ns,* η_p^2 = .007. A significant interaction effect was found however when examining map type x trial, *F*(1, 111) = 6.89, *p*<.05, η_p^2 = .05. Further analysis via the use of simple main effects showed that there was a significant effect of trial for Group Cluster, *F*(1, 111) = 4.11, *p*<.05. This confirms the impression of Figure 7.4, that participants in Group Cluster improved their performance from trial 1 to 2. There was no effect of trial for Group Grid, *F*<1. The effect of Map Type was not significant in either the first, (*F*<1), or second trial, (*F*(1, 111) = 2.28, *ns*). All other interactions were not significant [Trial x Counterbalance, *F*(1, 111) = 3.31, *ns,* η_p^2 = .027, trial x location, *F*>1, *ns,* η_p^2 = .002, Trial x Map x Location, *F*>1, *ns,* η_p^2 = .001, Trial x Map x Counterbalance, *F*>1, *ns,* η_p^2 = .006, Trial x Location x Counterbalance *F*>1, *ns,* η_p^2 = .001, Trial x Map x Location x Counterbalance, *F*>1, *ns,* η_p^2 = .002].

The time participants required to complete consistent compared to inconsistent exploration trials is presented in Figure 3.5. This graph reveals that participants within both conditions (Cluster /Grid) were slower during consistent trials compared to inconsistent trials (consistent trials *M*= 35.95s, *SD*= 26.47; inconsistent trials *M* = 27.67s, *SD*= 23.67). To examine differences between conditions and the effect of trial consistency during the exploration tasks, a 2 consistency (Consistent, Inconsistent) X 2 crime density (High, Low) X 2 geovisualisation type (Grid, Cluster) X 2 location (Mayfair, Camden) mixed design ANOVA was calculated. A significant main effect of consistency was found, *F*(1, 118) = 18.50, *p*<.01, η_p^2 = .14. This confirms that participants completed consistent trials more slowly than the inconsistent trials. No significant interaction between consistency and geovisualisation type was observed, *F*(1, 118) = 2.53, *ns,* η_p^2 =

.02. No significant interaction between consistency and location, *F*<1, *ns*, η_p^2 = .03 was seen. The three-way interaction between consistency, geovisualisation type and location was not significant, *F*(1, 118) = 1.12, *ns,* η_p^2 = .009. No main effects of geovisualisation type was recorded, *F*(1, 118) = 2.16, *ns,* η_p^2 = .018, nor was there a main effect of location, *F*(1, 118) = 3.59, *ns,* η_p^2 = .029. There was however a significant main effect of crime density, *F*(1, 118) = 8.21, *p*<.01, η_p^2 = .075. Participants were faster to identify low crime (*M* = 29.25s, *SE*=1.51) than high crime (*M*= 34.37s, *SE*= 2.28). No interaction between crime density and geovisualisation type was observed, *F*<1, *ns*, η_p^2 = .003, and no interaction between crime density and location was found *F*(1,118) = 2.69, *ns,* η_p^2 = .022. No 3-way interaction between crime density, geovisualisation type and location was observed, *F*<1, *ns,* η_p^2 = .001. No significant interaction was observed between crime density and consistency, *F*<1, *ns,* η_p^2 = .002. Overall it does not appear that geovisualisation type influenced participants' latency. Consistency had an effect but not in the anticipated direction. For example participants looking for the lowest street crime in a high crime area (inconsistent task) took less time than when searching in a low crime area (consistent).

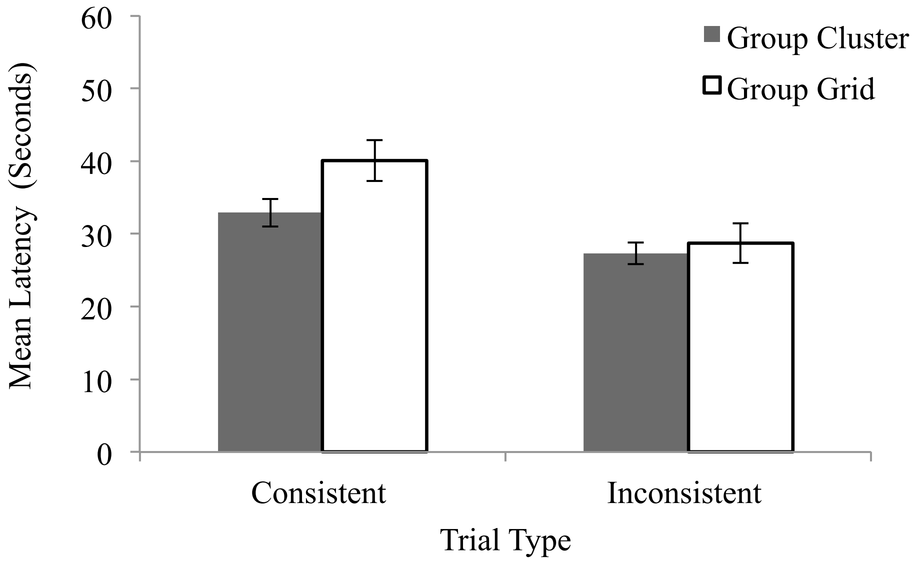


Figure 3.5. Participants' mean latency when completing the consistent compared to inconsistent exploration trials. Participants recorded greater latency within the consistent trials compared to the inconsistent trials, an effect more pronounced for Group Grid. Error bars represent the estimated standard error of the mean.

Participants' accuracy for each response during the exploration trials was also recorded. Participants' accuracy was reported as a binary score (correct/incorrect). Participants' accuracy within consistent and inconsistent trials is presented in Figure 3.6. From this graph it is apparent that participants were more accurate in the consistent rather than inconsistent trials, although no differences between groups are apparent. Due to the binary nature of the accuracy data a non-parametric comparison test was used to examine whether accuracy significantly differed between consistent and inconsistent trials. A Wilcoxon's test revealed that consistency did impact overall accuracy, z = -2.90, p<.05. This supports the impression of Figure 3.6. that participants were significantly more accurate when searching for consistent targets. This demonstrates that despite participants being faster during the inconsistent trials, they were more accurate during the consistent trials.

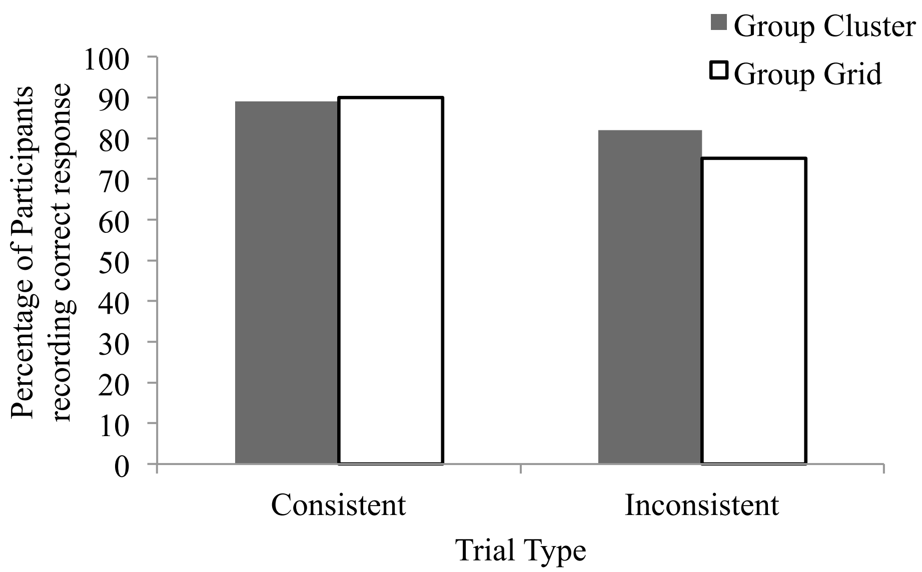


Figure 3.6. Participants' accuracy when completing each of the exploration trials based on consistent versus inconsistent trials. Participants recorded greater accuracy within the consistent trials compared to the inconsistent trials, an effect more pronounced for Group Grid.

To examine the difficulties that participants encountered when using the geovisualisations, content analysis was conducted on open responses from participants' reflective questionnaire. Figure 3.7. presents the results in response to the question *"Can you describe any difficulties which you encountered when using the system?"*. Generated themes, and prevalence rates, for both geovisualisation type (Cluster/Grid) are presented. Little difference, in recorded themes and prevalence rates, were apparent for either geovisualisation. The most prevalent source of difficulty was related to clarity within the display, including "*move the crime rates so they do not cover the road names*", an issue highlighted by 34% of Group Cluster and 42% of Group Grid. The second key emergent theme was that of disorientation, or feeling lost within the display. Participants reported "*When you zoomed in it was easy to lose where you were*" and "*(I) lost whereabouts on the map I was meant to be looking when I zoomed in*". Issues that related to disorientation included participants losing track of their specific location and their overall orientation as they zoomed between the layers within display. Issues related to disorientation and feeling lost within the display was reported by 20% of Group Cluster and 25% of Group Grid. Additional difficulties participants encountered included issues relating to understanding, commonly not understanding the symbolisation used within the geovisualisations and a lack of knowledge of how the visualisation was related to the underlying base map, an effect reported by 13% of Group Cluster and 16% of Group Grid. Whilst limited differences in the themes that emerged were apparent between the two groups, it is clear that Group Grid reported more difficulties.

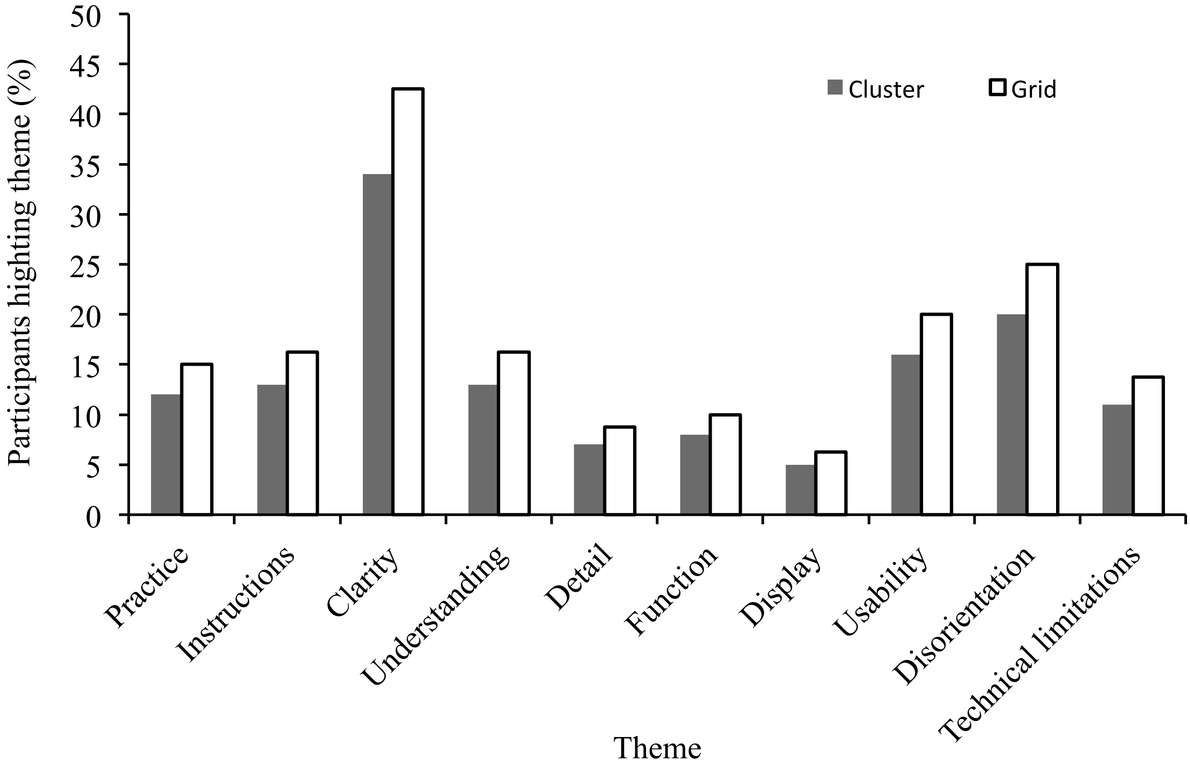


Figure 3.7. Content Analysis generated themes and prevalence rates for Group Grid and Group Cluster, displaying commonly encountered difficulties. Little difference can be observed between conditions.

Discussion

This study investigated whether geovisualisation type influenced participants' interactions with the displayed information, including their speed and accuracy when interpreting the presented data. Results suggest that the cluster visualisation was initially more difficult for participants to interact with, as indicated by high initial latency, this difficulty was however reduced in subsequent trials, with Group Cluster becoming faster than Group Grid, whose times did not significantly differ between trials. No other differences between geovisualisations were identified, suggesting that once participants' overcame this initial difficulty, both geovisualisations are suitable tools. This study also sought to investigate whether consistency impacted participants search time and accuracy. Results suggest that participants were faster completing inconsistent rather than consistent trials. In contrast, results measuring accuracy support that participants' were more accurate when examining consistent rather than inconsistent trends, for example high crime within high crime areas. This finding is potentially indicative that participants engaged in speed accuracy trade-offs, potentially showing that the inconsistent trials were more difficult. Qualitative findings suggest that participants' main sources of difficulty were related to clarity within the display and disorientation within the map, with participants reporting difficulty in maintaining knowledge of their position within the wider environment.

Results from the basic competency tasks suggest that although participants showed increased latency when using the cluster geovisualisations initially, they became more efficient with practice. The time Group Clusters' required to complete the first basic competency trial was significantly longer than the time required to complete the second basic competency trial. In contrast no improvement was seen for latencies in Group Grid. The finding that Group Grid recorded reduced latency within the first trial offers partial support for research highlighting the importance of colour within geovisualisations (Harrower & Brewer, 2003). Harrower and Brewer suggest that colour can act as a *"sign vehicle"* (*p*27) to users of geovisualisations allowing them to readily interpret the information which is presented. Whilst Garlandini and Fabrikant (2009) note that the use of colour is based more on convention than empirical evidence regarding usability, this study demonstrates an effect of colour. Results from this study supports the view that choropleth maps are suitable for tasks engaging novice users as participants were able to interact with this geovisualisation efficiently from the first presentation. This finding is consistent with results from Boscoe and Pickle (2003), who in a map use and rating task, found that choropleth maps were accurately used and highly rated by users.

The finding that participants' were able to interact with the choropleth grid geovisualisation more rapidly during the initial basic competency trials may sound counterintuitive. Prior to examining the geovisualisation itself, participants were also required to scan the geovisualisation legend. Fabrikant and Goldsberry (2005) found evidence, using eye tracking methodology that legends were one of the most salient aspects of a geovisualisation, attracting a high degree of visual attention. The requirement to explore a legend was not present when using the cluster geovisualisation. In the present study, it was found that users were able to immediately and efficiently interact with the choropleth grid visualisation without extended exposure time or repeated trials. Similar findings are also apparent in previous studies however. Pickle (2003) found that legends were largely rated as unimportant by users, in that users wanted to proceed quickly to examining the map display rather than legends. Combined with the findings of Fabrikant and Goldsberry (2005) it is possible to suggest that participants did not require a significant proportion of time examining the legend provided with the choropleth grid. In addition, the legend and colour scheme used within this study matched standard practice, with high data density being associated with red and cooler colours of orange, yellow and cream being used to indicate lower density (Brewer, 2003). This pattern is likely to be well known to the participants, so that they did not need to spend time understanding this pattern or examining the legend (Harrower & Brewer, 2003).

Participants' greater accuracy within consistent trials is of interest when considering that participants were also slowest during these trials. When these findings are considered in parallel, it is possible to suggest that speed-accuracy trade-offs (Wickelgren, 1977) may be occurring. Speed-accuracy trade-offs occur when individuals make fast decisions at the expense of overall accuracy (Wickelgren, 1977). Speed-accuracy trade-offs have been identified in numerous studies including visual discrimination tasks (Liu & Watanabe, 2012). Speed-accuracy trade-offs have also been introduced within research examining the use of digital maps. Wilkening (2010) required participants to rate a series of maps, including satellite imagery and roadmaps within time limited and time unlimited conditions. In a second study, participants were asked to use 24 different maps to plot the fastest route between two locations under time limited conditions. Although Wilkening found no significant difference between time condition and accuracy, accuracy was higher in the time unlimited conditions. Within the current study, participants were not required to complete the task within set time constraints; a key component of speed-accuracy tests, participants may have felt under time pressure to complete the tasks, which, in turn, may have impacted accuracy.

When examining the difficulties which participants encountered using the geovisualisations two key issues that were raised were related to a greater desire for clarity within the displays and feelings of disorientation. Clarity issues largely revolved around map design issues, for example, data obscuring road names, and a desire for greater image resolution which whilst useful feedback for map designers is largely beyond the scope of the present research. It was clear from the results that issues relating to maintaining orientation were common. Participants remarked that maintaining orientation within the visualisation was difficult, for example

"[it was difficult to] Zoom in and out whilst keeping track of your coordinates".

Participants frequently commented that they experienced disorientation, with 20% of Group Cluster and 25% of Group Grid suggesting they experienced disorientation. Nojima and Shingaki (2000, cited in Suzuki, 2012) found that users of digital environments often reported disorientation whilst undertaking virtual searches. It was found that rather than acting to support participants the inclusion of data within the geovisualisation acted to confuse users. Participants highlighted difficulties due to the requirement to interact with multiple layers, for example

"I found it confusing as the picture continuously changed images throughout when zooming in".

This suggests that the act of zooming between the different levels of the visualisation influenced interactions. Geovisualisations are immersive environments with great navigational freedom; however users must integrate the multiple data layers with the underlying base map, simultaneously tracking changes within both the data and the geography. If they fail to do this they risk losing track of their overall position. Bowman, Koller and Hodges (1997) highlight that navigation within a digital 3D environment is unlike everyday navigational experiences, a difference magnified by the use of semantic zoom (Perlin & Fox 1993, Buring, Gerken & Reiterer, 2006). Bowman et al., also suggests that the use of any technique which can result in a large change within the environment will likely lead to disorientation. The changes in symbolisation between the different layers within the visualisations therefore are likely to be a factor in participants' disorientation. Disorientation is however a subjective experience (Smith & Marsh, 2004), although 20% of Group Cluster and 25% of Group Grid reported feelings of disorientation, it is not clear the extent to which this influenced their interactions. It is worth noting that despite the large number of participants reporting disorientation, the majority of participants were able to complete the tasks. Whether individuals would continue to use a geovisualisation outside of test conditions after experiencing difficulty or disorientation is, however, unclear. Peuquet (2002) suggests that individuals will abandon information systems before being able to take advantage of the available information if they encounter difficulties. It is clear from these findings that disorientation is impacting users of geovisualisations and can partially account for negative user experiences, confusion when using the available tools and, as demonstrated by participants' prior lack of experience using geovisualisations, a reluctance to engage with the available tools.

Although this study was considerably more limited in the demographics of participants than Experiment 1, it is clear that similar difficulties and issues are emerging. Despite the inclusion of interactivity and navigational freedom, users persisted in reporting that they struggled to maintain orientation. This suggests that participants struggled to link the different layers of data within the visualisation. This finding indicates that interventions are required to assist users in maintaining a sense of orientation. This suggests that similar to the virtual nested environments, participants struggle to maintain a consistent link between the different layers of data and the base map. Based on participants' comments regarding clarity, the data provided within the geovisualisation acted to hinder, rather than help, participants maintain a sense of where they are. This is because the presented data can partially obscure cues traditionally used for navigation and orientation. Thus, whilst Harrower and Sheesly (2007) argue that additional landmark cues may benefit users, it is clear that these cues must be added within the environment so that they are visible at all levels of the geovisualisation and never obscured by the presented data. Harrower and Sheesley suggest that a possible option for providing additional orientation context is the use of an overview map, providing a clearer link between the local orientation features of the current zoom level and the global features of the larger map. Hornbaek, Bederson and Plaisant (2002) showed however that participants can complete tasks within interactive geovisualisations without the need for an overview map. In a comparison between multiple geovisualisations, Hornbaek et al. found that no significant difference regarding participants accuracy when using geovisualisations with and without an overview map. They found that when legends were completely omitted there was no influence on accuracy but participants completed tasks significantly faster. Hornbaek et al. argues that within geovisualisations, additional context is provided by the increased layers of data so that overviews are not needed. However, Hornbaek et al. did find that providing participants with an overview affected participants rating of the geovisualisation, with 80% of participants indicating a preference for the geovisualisation with the overview. Although overviews are beneficial to users' confidence, Hornbaek et al. suggest that overviews may not be the best tool to support users in remaining oriented do to the lack of observed differences relating to accuracy when using the geovisualisations. Tools to help users remain oriented as they move between multiple layers within geovisualisations would be beneficial based on the work of Hornbaek et al. (2002), Harrower and Sheesley, (2007) and the current study.

Other than initial differences in latency for the basic competency tasks, no significant differences between geovisualisation types emerged as part of this study. This is unlike results from Experiment 1 that demonstrated that the heat choropleth map was more accurately interpreted than the cluster geovisualisation. Although more research is needed, it may be that the differing levels of accuracy between geovisualisation types identified in Experiment 1 was a partial consequence of the lack of interactivity within this study, further research is needed to examine this finding in greater detail.

Conclusion

This study examined participants' use of alternative interactive geovisualisations, a cluster geovisualisation and a choropleth grid geovisualisation. However, limited differences were observed in the results for the different symbolisation techniques used within the geovisualisations. Consistency of target and area impacted both latency and accuracy, with consistent area target relations being associated with more accurate, albeit slower, responses. One potential explanation that has been proposed within this study is that a speed-accuracy trade-off is impacting participants' interactions. Additionally it was found that issues' relating to disorientation was a common difficulty encountered by participants', and requires the attention of map designers.

From the evidence which has emerged within Chapter 2 and Chapter 3, it is apparent that users of geovisualisations require assistance in maintaining clear links between the different aspects of the environment, the multiple data layers and the base map, within the geovisualisations. This result suggests that users would benefit from the link between the elements being strengthened. As geovisualisations are complex multidimensional environments, it is difficult however to isolate orientation and difficult to implement and control potential interventions. Chapter 4 – 7 will therefore examine the potential of environmental cues, not within geovisualisation, but rather within a digitised representation of the real world.

Chapter 4

Facilitating Orientation within a Virtual Nested Environment

Experiment 3 – Orientation within a Virtual Building. The role of a Map.

As seen within Chapter 1, effective orientation within virtual environments is a significant challenge (Bowman, Davis, Hodges & Badre, 1999). Additionally, it was seen that effective orientation within real world nested environments is also a considerable challenge as participants struggle to track changes within both their local and external environment (Wang & Brockmole, 2003; 2003). The current study seeks to explore the effect of combining these two documented sources of difficulty and investigates the extent to which participants, undergraduate students, are able to orient within a virtual nested environment. This study will also investigate whether providing participants with a paper map of the environment acts to facilitate their ability to accurately orient, as has been demonstrated within the real world (Thorndyke & Hayes-Roth, 1982).

The environment chosen for this experiment was a virtual model of the Shackleton building, University of Southampton, and its surroundings; a location participants' would be expected to be familiar with. Research has documented that familiarity with an environment improves participants' ability to navigate and orient (Ruddle, Payne & Jones, 1997). By using an environment which participants are already familiar, it will be clear that recorded orientation difficulties are a consequence of the effective use of digital and nested environments (Bowman et al., 1999; Wang & Brockmole, 2003) rather than as a consequence of participants failing to sufficiently learn about their environment during the initial acquisition phases.

Despite all participants being familiar with the university campus and the Shackleton building, participants have no experience of the virtual model or the trials they will be exposed to. This study will therefore investigate the role of direct room level experience within orientation performance. It is worth considering the value of the experience that participants gain as they explore the environment and specifically from visiting a location. As noted previously, users of virtual environments are restricted to visual cues (Hartley, Trinkler & Burgess, 2004), and do not have access to idiothetic information which supports orientation decisions within real world environments (Reiser, 1989). Research has however indicated that visual cues are sufficient to allow for spatial updating to occur (Riecke, Cunningham & Bulthoff, 2007; Wan, Wang & Crowell, 2009). Using a motion chair, Riecke, Cunningham and Bulthoff (2007) demonstrated no significant difference in the orientation performance of participants who did and participants who did not have access to idiothetic cues during a tour of a virtual town. This suggests that visual cues can provide sufficient information to allow individuals to place visited locations within their spatial array and allow for accurate orientation. Extending this research, it would be predicted that experience of a location, for example by visiting it previously during acquisition, should result in lower recorded orientation error than if the location had not been visited.

When exploring nested environments, such as building within a university campus, in the real world, it is clear that two distinctive view types exist. External views allow individuals a view of their external environment, providing external landmark cues to aid understanding of overall location. In contrast, internal views provide no view of the external environment meaning that external landmark cues are unavailable. The importance of visual cues when exploring an environment should not be overlooked and research has stressed the importance of such information (Loomis, et al., 1993; Ohmi, 1996). It would be predicted that a view of the external environment should help to maintain the allocentric spatial relationships that exist between the local environment of participants' location within the building and their position relative to external landmark cues. It would consequently be predicted that when participants have access to a view of the external environment, for example within an external-facing room, they would record lower orientation error than if they did not have access to this visual information, for example within internal-facing rooms overlooking the inner courtyard.

The role of a map in supporting navigation has been documented. Maps have been shown to assist participants' ability to successfully learn the layout of an environment both within real life (Thorndyke & Hayes-Roth, 1982) and within virtual environments (Darken & Sibert, 1996; Ruddle, Payne & Jones, 1999). Thorndyke and Hayes-Roth explored the differences in spatial learning as a result of map use to those with direct experience. Using a variety of spatial tasks, Thorndyke and Hayes-Roth compared participants who had experience of a building for 1 to 2 months, 6 to 12 months, or 12 to 24 months to a group of participants who had never been to the building but had studied a map of the environment layout for an hour. They found that although the map users made fewer errors estimating Euclidian distances and were more accurate at judging object locations, compared to participants with 1-2 months of experience within the building, no differences were seen between the map users and participants with greater experience. Furthermore, it was seen that the map use group made greater error when calculating route distances compared to participants with experience of the environment, suggesting that experience enabled participants to make more accurate spatial judgments. In addition, the map use group made greater error during an orientation task whereby participants were asked to point to an unseen target location within the environment, compared to experienced participants. As participants' navigational experience within the building increased so did orientation accuracy, with participants with between 12 – 24 months of experience recording highest orientation accuracy. Despite the poor performance of the map use group, these results hint that maps can be used to facilitate performance, for example, despite never visiting the building before, map users performance was not significantly difference from participants with 1 – 2 months of experience within the building.

Although Thorndyke and Hayes-Roth (1982) found that direct experience helped performance within an orientation task more than access to a map, Uttal (2000) argues that maps help users perceive a world beyond perception, allowing participants to “see” parts of their environment which would otherwise be occluded and not visible. Within orientation tasks, provided participants are aware of their current location on the map and can successfully ensure their map is within the correct heading then they should be able to identify the location of all potential targets within the environment. Based on the claims of Uttal (2000), providing a map of the environment should help reduce orientation error, even when participants do not have prior experience of a location. As all participants within the current study will have the same level of experience exploring the virtual model, it would be predicted that participants provided with a map would be more accurate during the orientation tasks due to the presence of the additional aid. It would be anticipated however that this effect would be most pronounced within the unvisited rooms.

This study examines the extent to which participants are able to remain oriented within a familiar nested virtual environment. In addition, this study examines whether providing a paper map of the environment assisted participants’ ability to track their position. To complete this task, a virtual model of the Shackleton building, University of Southampton, and its surroundings was created (Figures 4.1 – 4.3). The model allowed participants to navigate and explore the environment using standard keyboard arrow key controls.

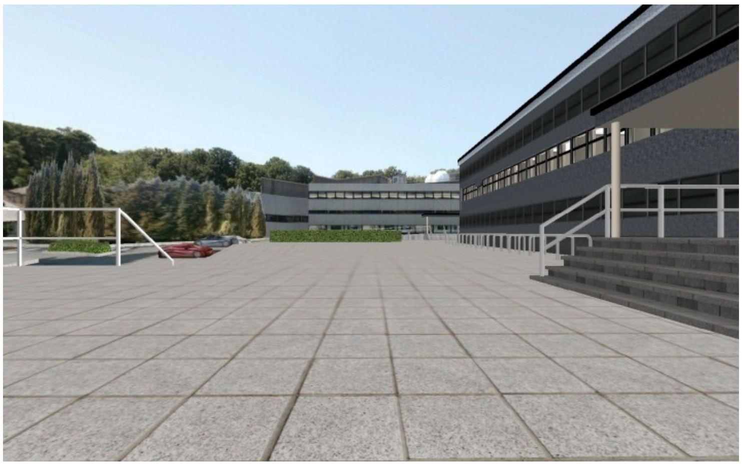


Figure 4.1. View of external environment during exploration seen by participants.

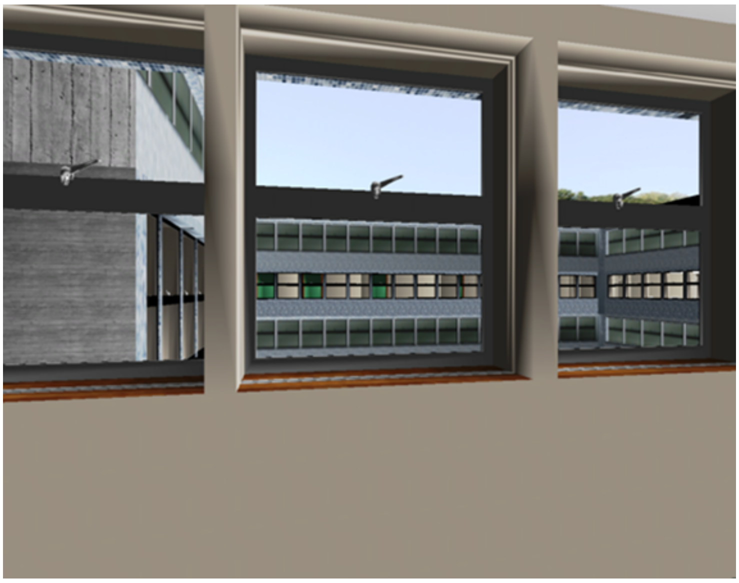


Figure 4.2. View from one of the internal-facing visited trial rooms. It can be seen that no external orienting cues are visible.

Figure 4.3. View from inside the model building seen during exploration, above the main entrance and overlooking the car park. The external environment can still be clearly seen.

Participants were split into two groups, Group Control and Group Map. Although both groups explored the same environment, participants within Group map were also provided with a map of the environment. Previous research has indicated that when exploring both nested environments and virtual environments individuals struggle to maintain orientation either due to a limited capacity to store visual-spatial information (Wang & Brockmole, 2003) or due to a lack of idiothetic information (Reiser, 1989). It was hoped that the inclusion of the map within Group Map would reduce the difficulty associated with orientation within the environment and consequently reduce orientation error.

All participants explored the model during two acquisition phases before completing a series of four orientation test trials. For each orientation test trial, participants were placed within a room in the model, before being asked to turn to face an external target which they would have seen during exploration, but which was not visible during the trial. Example targets included the physics building, car park and the main entrance of the Shackleton building. The map of the environment provided to participants is presented within appendix 4.1. Of the rooms that participants were placed in, two had been visited during acquisition. This enabled the researchers to examine the role of short term experience in orientation accuracy. Furthermore, two of the rooms provided participants with an external view overlooking the wider campus, allowing the use of external landmark cues, whilst two overlooked the inner courtyard.

Based on previous literature the following hypotheses can be suggested:-

1. Regardless of group, participants will record lower mean orientation error within rooms that they had visited previously during the acquisition phases compared to the unvisited rooms (Riecke, Cunningham & Bulthoff, 2007).

2. Regardless of group, participants will record lower mean orientation error within the external-facing, compared to the internal-facing rooms (Loomis, et al., 1993; Wang & Brockmole, 2003).
3. Group Map will record lower overall mean orientation error than Group Control, especially within the unvisited locations (Uttal, 2000)

To summarise, following two acquisition phases whereby participants explored the environment, participants completed four orientation test trials in rooms that were classified as Unvisited/External-facing, Unvisited/Internal-facing, Visited/External-facing and Visited/Internal-facing. Regardless of condition, it would be anticipated that participants would record lower orientation error if they had visited the room previously during the acquisition phases as they should have a greater understanding of the rooms' position within the larger spatial context. Participants would also be anticipated to record lower orientation error when they have an external view to the wider campus environment due to the presence of external landmark cues. If providing a map aided participants' in remaining oriented, it would be expected that Group Map would record lower orientation errors than Group Control.

Method

Design

This study used a mixed design. The independent variables were room type (Internal-facing/ External-facing), experience (Visited/ Unvisited) [within] and condition (Control/ Map) [between]. The dependant variable was orientation error, as measured by pointing accuracy across four orientation test trials. Participants were randomly allocated between the two conditions.

Participants

Participants were 30 psychology undergraduate students, from the University of Southampton, who completed the study in exchange for credit towards a departmental research participation scheme. Group Control contained 13 female participant and two male participants. Group Map contained 14 female participants and one male participant. Due to the limited age range inherent within the sample, age demographics were not collected. Participants were recruited via the use of an intranet recruiting system. All participants had normal or corrected normal vision. Participants had experience of the real campus, but not of the model. As the rooms chosen for the study were research offices, participants would not have had experience visiting any of the test rooms within the real world

Apparatus

The study took place within a windowless research cubicle, measuring 2.4 metres in length by 1.3 metres wide, with a height of 2 metres. The cubical contained a single desktop computer. The computer used a standard Windows 7 operating system, with keyboard and mouse, placed on a 1.3m wide desk in the centre of the rear wall. The computer was connected to three identical 15-inch LCD monitors. The monitors were placed horizontally so that the displayed image was shown continuously across all three screens.

A virtual model of the Shackleton Building, University of Southampton, and its surroundings was created especially for this study. This model was developed by Dr Matt Jones, University of Southampton, using 3DSMax 2012. The programme placed the participants within the environment and offered a first person perspective (Figure 2.1 – 2.3). The model enabled participants to freely explore the surrounding environment and the third floor of the Shackleton building. The remaining areas of the campus, including other buildings and additional floors within the Shackelton building were not accessible. Participants controlled their movement using the “FORWARD” “LEFT” and “RIGHT” arrow keys, but could not look up or down, or interact with items within the environment. Participants were instructed not to use the “BACK” arrow key in order to better simulate real life movement.

Procedure

Upon entering the research cubical, participants were presented with an information sheet describing the aims of the research and outlining participants’ ethical rights and a consent form. The experimenter verbally outlined the study to the participant and verbally restated participants' ethical rights. Participants were required to consent to participate before the experiment began. The experimenter explained the procedure of the acquisition phases of the study to the participants, ensuring that the participant was happy with the controls of the virtual environment and answering any questions the participant may have had. The Experimenter left the room prior to the start of the first acquisition phase.

The procedure used for both groups within this study was identical with the exception that participants within Group Map also had access to a paper map of the environment which was presented to participants prior to the start of the study, and which was available throughout both acquisition phases and during all test trials. The map presented to participants is available in Appendix 4.1. The map showed the layout of the surrounding campus areas, including all potential targets for the orientation trials, and was sufficient to cover the total area that participants could explore within the acquisition phases. As this map was used to help participants to understand the external campus environments, the internal layout of the building was not visible; however the approximate position of the four trial rooms was marked on the map. Participants were not directly told that the numbered locations on the map corresponded to the test trial rooms. Participants were informed that they were free to use the map as much as they wished, and were free to refer to the map whenever they wished.

The study comprised of two trial phases, acquisition phases and orientation test trials. Participants completed two acquisition phases to familiarise themselves with the environmental layout and four test trials. For the first acquisition phase, participants were required to explore the external campus environment, allowing participant to see, but not enter, surrounding buildings, including the physics building and the student union.

Participants were provided with written instructions regarding a route to take within the environment. This route ensured that participants saw and identified all visible landmarks in the surrounding area and did not become trapped or lost. As the participants controlled movement, they were free to divert from the suggested route if they wished to explore further. A copy of the instructions (Appendix 4.2) and an image of the route participants were advised to take (Appendix 4.3) are available within the appendices. Once participants had explored the surrounding environment, they were instructed to make their way back to the starting location and to indicate to the experimenter that they were happy to proceed to the next trial. For the second acquisition phase, participants were required to enter the virtual building and to explore the third floor of the model. Participants' were again provided with a route to follow to ensure that they had visited key locations within the building and looked out of key windows to view external landmark cues. Instructions (Appendix 4.4) and overall route (Appendix 4.5) are available within the appendices. Neither acquisition phase was timed; participants were free to explore the environment for as long as they wished. Following completion of the two acquisition phases, participants notified the experimenter, who had been waiting outside of the research cubicle they had finished these phase of the study.

Prior to the start of the test trials, the experimenter re-entered the cubical and verbally outlined the orientation task to participants. Participants were informed that they would be required to complete four orientation test trials, whereby they would be digitally placed within a room in the building, which they may or may not have been in previously and asked to turn to face a non-visible, but before seen, external target. During each of the test trials participants were not able to leave the room they had been placed in, however could move within the room. Two of the trial rooms selected had a view overlooking the external campus environment, enabling the use of external landmark cues. Two of the rooms, however, overlooked the inner courtyard of the building, limiting the available cues. The cues provided were however always sufficient to complete the orientation task. The rooms selected for the test trials were empty of features other than elements of building architecture, for example doors and windows. Participants they were verbally informed of the required target by the experimenter at the start of each orientation trial. Orientation trials were not timed and participants were free to take as long as they wished. Participants had complete freedom of movement within each test room, but could not leave the room. The target directions were symmetrical with the walls of the test rooms such that if a participant's estimate of an external target indicated the centre of a room wall, this would align with the centre of the external target. Participants completed the four test rooms sequentially and were presented with a different target within each room. Participants were not offered feedback on their performance during the trials. Once participants had completed all four orientation test trials, they were verbally debriefed by the experimenter, before being presented with a debriefing form which outlined the aims of the study. Before leaving participants were informed of their performance within the study.

Results

Data Analysis

The Virtual Navigation Software tracked participants' movements within the virtual environment at all times. Participants' locations and route taken, during the acquisition phases and their orientation during both acquisition phases and test trials were provided by the programme output. Participants chosen direction was therefore provided as their final direction coordinate within the programme output.

For the orientation test trials participants' orientation score was compared to the location of the presented landmark target and participants' deviation from the target was recorded as an absolute error. Because participants received an absolute error, based on the number of degrees they were pointing away from the target, the maximum orientation error participants could record was 180°. Figure 4.4 represents this calculation for clarity.

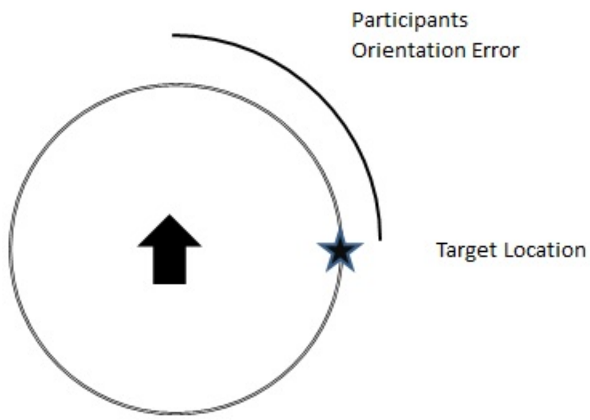


Figure 4.4. Participants orientation error calculation. The arrow represents the direction participants faced during the orientation trial. The smallest angular difference between the target and participants direction was calculated. In the example above, this is approximately 90˚.

All statistical tests were evaluated with respect to an alpha value of .05.

Figure 4.5 presents the mean orientation error of Group Control and Group Map. It can be seen that although Group Map were more accurate within the unvisited internal-facing room (Group Control mean error = 87.31°, Group Map mean error = 65.21°) and the visited external-facing room (Group Control mean error = 25.24°, Group Map mean error = 11.93°), Group Control were more accurate within the visited internal-facing room (Group Control mean error = 24.87°, Group Map mean error = 49.71°). Although Group Map was more accurate within the unvisited external-facing room, this effect was small, and no clear consistent differences can be seen between groups (Group Control mean error = 21.95°, Group Map mean error = 21.01°). Despite participants within Group Map recording lower error than Group Control, from this figure it does not appear that the map consistently improved participants' ability to orient. Regardless of group however, it appears that participants recorded lowest error within rooms that had been visited previously during acquisition, and external-facing rooms that provided a view of external landmark cues.

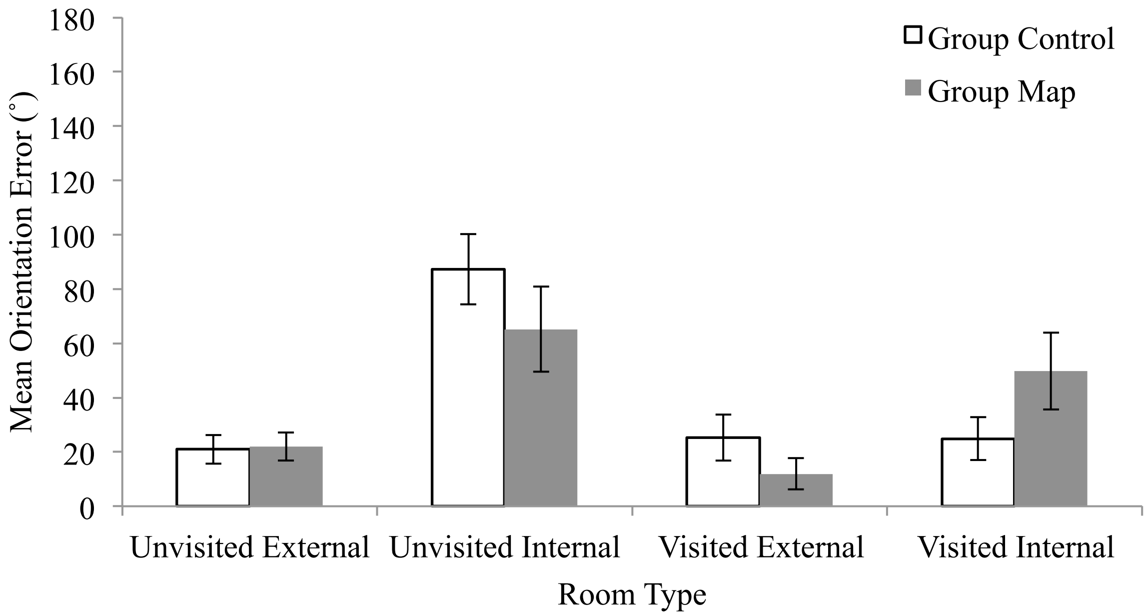


Figure 4.5. Mean orientation error for participants within Experiment 3. From this graph, it is clear that access to the map failed to consistently facilitate orientation performance across the four trials. No clear consistent differences between Group

Control and Group Map are apparent. Error bars represent the estimated standard error of the mean.

A 3-way mixed design analysis of variance (ANOVA) was used to explore the effect of experience (Visited/ Unvisited), room type (Internal-facing/ External-facing) and condition (Control/ Map). A significant main effect of experience was found, $F(1, 26) = 13.09, p<.05, \eta_p^2 = .34$. Participants' recorded significantly higher error in the rooms that they had not visited during the acquisition phases. There was also a significant main effect of room type, $F(1, 26) = 30.75, p<.05, \eta_p^2 = .54$. Participants' recorded significantly higher errors within the internal-facing rooms. There was not, however, a significant effect of condition, $F<1$, *ns,* $\eta_p^2 = .003$. Access to a map did not significantly affect performance within the orientation trials. A significant interaction was found between experience and room type, $F(1, 26) = 6.92, p<.05, \eta_p^2 = .21$. Participants recorded highest error within the internal-facing room that they had not visited previously. This is supported by simple main effects analysis (Keppel, 1973) which revealed a significant effect of room type within the unvisited rooms, $F(1, 52) = 33.02$, $p<.05$. Participants recorded higher error in the internal-facing unvisited rather than external-facing unvisited room. Further analysis also showed a significant effect of experience within the internal-facing rooms, $F(1, 52) = 18.88, p<.05$. Participants recorded significantly higher error within the internal-facing room that had not been visited previously during the acquisition phases compared to the visited internal-facing room.

A significant 3-way interaction was found between experience, room type and condition, $F(1, 26) = 30.75$, $p<.05$, $\eta_p^2 = .16$. Further analysis via the use of simple main effects revealed no effect of condition across room type and experience (External-facing Unvisited, $F<1$, *ns*, Internal-facing Unvisited, $F(1, 104) = 2.34$, *ns*, External-facing Visited, $F<1$, *ns*, Internal-facing Visited, $F(1, 104) = 2.95$, *ns*) suggesting again that access to a map did not consistently aid orientation in Group Map.

Discussion

It was found that participants recorded lower errors in rooms that they had visited previously during the acquisition phases and external-facing rooms that had a view overlooking the external environment. Results demonstrate however that providing participants with a paper map of their environment was not sufficient to significantly reduce orientation error. The addition of the map was not sufficient to overcome the difficulty related to orientating within rooms that had not been visited previously and rooms which lacked an external view. This suggests that participants were unable to directly relate their position within the building to their position within the map.

Participants recorded higher orientation error within rooms that had not been visited previously. This finding demonstrates that experience visiting a location previously helps participants place the location within the wider spatial context of their environment. This finding matches the work of Christou and Bulthoff (1999) who asked participants to explore a virtual building model whilst searching for several key landmarks. Results suggested that participants were more accurate from viewpoints that they had explored previously rather than novel locations. Key differences within this study were use of a familiar environment and the level of training participants received prior to the orientation trials. Christou and Bulthoff (1999) used a virtual model of an attic within a real house which participants had not visited previously; furthermore they note that within their study the training phase was extensive for a simplified environment, lasting approximately 30 minutes. Within the present study, acquisition phases were much shorter. Although participants were experienced with the campus environment, participants did not have experience of the model or the trial rooms prior to the study. The finding of improved performance within the visited locations suggests that experience is beneficial for orientation accuracy.

Participants recorded higher orientation error within internal-facing rooms, overlooking the internal courtyard, compared to external-facing rooms which overlooked the main campus. Within the internal-facing rooms, participants were limited by the cues they could use; participants could not see the wider external environment. External landmarks, for example the student union and the physics building, were not visible. As such participants were required to look into rooms that they had visited previously to calculate their current position, for example looking to see the large computer room. Although the cues that were available within the internal spaces were sufficient to calculate position, and for Group Map, the position of the rooms was marked on the map, the lack of clearly visible external landmarks dramatically reduced performance within the internal-facing rooms. This finding supports evidence of the importance of landmark cues in spatial knowledge (Siegel & White, 1975). That participants’ performance differed between the internal-facing and external-facing rooms also supports evidence positing the existence of multiple spatial reference frames, specifically local and global reference frames (Meilinger, Riecke & Bulthoff, 2013). Within the external-facing rooms participants could see the wider university campus, grounding the external environment within participants’ local reference frame. It is likely that this grounding enabled participants to more accurately judge the position of the external landmark targets, even when the target of interest was not visible. This is supportive of Meilinger, et al. who found that participants would rely on local reference frames to complete survey tasks within a virtual environment object localisation task, similar to the task employed within the current study. The importance of local reference frames was also apparent within the work of Wang and Brockmole (2003), who identified that participants were more accurate at judging the position of targets within their immediate local reference frame than judging the position of non-visible targets within the wider campus environment, part of their global reference frame. From the results of the current study and previous work (Christou & Bulthoff, 1999), it would be possible to predict that if Wang and Brockmole (2003) had allowed participants a view of the external campus environment, prior to orientation trials; recorded orientation error would have been reduced.

The finding that the map failed to facilitate participants' ability to orient is not novel. Several other studies have reported similar null results. Sjolinder, Hook, Nilsson and Andersson, (2005) compared younger mean range and older mean range participants ability to navigate within a virtual supermarket. As part of the virtual environment, half of the participants could see an overview map indicating the overall environment shape, boundaries, walls and their current position. Participants were instructed to navigate within the virtual supermarket and "purchase" a list of items. Participants were informed to complete the task as naturally as possible and were told to travel at their own pace. Sjolinder et al. found that the inclusion of the map did not facilitate participants' ability to navigate or orient within the virtual supermarket. It was found however that younger participants consistently outperformed the older participants, recording reduced latency and a reduced number of actions required to complete the task. The inclusion of the overview map did not reduce the age gap or facilitate the performance of either group.

Sjolinder et al. does note however that the inclusion of the map was effective at improving participants' qualitative interactions with the digital environment. They found that participants reported feeling less lost as a result of having the map available to use. Although this was not directly assessed within the current study, this finding suggests that the maps do not directly facilitate performance but rather confidence. It is clear however from the work of Sjolinder et al. and the results of the current study that more effective orientation aids are required within complex internal spaces to facilitate orientation.

Research examining virtual environments and maps has previously found that maps can be effective, albeit limited aids. Parush and Berman (2004) investigated participants' ability to navigate and orient within a virtual model of a simple indoor space consisting of four rooms. They found that participants who learnt the environment with access to a map but no landmarks performed better on a series of orientation trials whereby they were required to turn to face a series of non-visible targets than participants who explored the environment with no landmarks. Participants who were provided with landmark cues and a route list however outperformed the map group. This suggests that although the maps can help facilitate orientation, other interventions are more effective, including the inclusion of additional landmark cues. Although Parush and Berman only examined participants' ability to orient within the internal environment and did not include a nested component, as was included within this study, it is clear that the impact of a map in facilitating orientation performance is lower than would be anticipated.

There has been considerable research demonstrating the importance of alignment effects within map use studies. Montello, Waller, Hegarty, and Richardson (2004) argue that even if an individual has a perfect understanding of the configuration of their environment, becoming disorientated within their local position will result in poor tasks performance. Montello et al. (2004) compared the spatial knowledge participants gained from real environments, virtual environments and maps. They required participants to learn two floors of a building from either a map of the layout, direct experience within the building, or by interacting with a virtual model of the environment. Montello et al. found that learners within the map group performed worst in situations whereby their current view did not match their learnt orientation. Related to the current study, orientation specificity within Group Map may help to suggest why the map failed to facilitate performance. The internal-facing unvisited room was associated with greatest orientation error; it is likely that due to the lack of an external view or previous experience participants struggled to accurately link their position to a position on the map, rendering it not useful as an aid.

This study extends the work of Montello et al. (2004) as rather than examining learning using virtual environments and maps in isolation, this study examines them in compound. Aretz and Wickens (1992) investigated the effectiveness of maps as aids within virtual environments and found that they were only effective when the map remained oriented within a forward up position, that is that the view forward of the navigator is upwards on the map, otherwise they note that the map user is unable to effectively match the map and real world orientation headings, leading to the map becoming misaligned with the real world. Similarly, Levine Marchon and Hanley (1984) found that even with maps with clearly marked “You are Here” labels, participants were still highly inaccurate and recorded high latency if the map was not aligned with the participants heading. Previous research (Rossano & Warren, 1989) has shown that individuals are unable to make accurate direction and orientation judgements when this relationship between map and real location breaks down.

Results from both this study and previous research suggest that the inclusion of a map has mixed outcomes. Whist it appears from previous research that the inclusion of a map does facilitate the acquisition of survey knowledge; maps seem to have reduced benefit within orientation tasks. This finding is consistent both within real world tasks (Thorndyke & Hayes-Roth, 1982) and digital environments (Sjolinder et al., 2005). The current study added further evidence that free standing maps are not a sufficient aid when orienting within nested environments, extending previous research which has largely focused on spaces with one dimension, for example external or internal environments only.

It should be noted that this study only explored the role of a free to use map, which could be used concurrently during the acquisition phases and orientation test trials. The responsibility for successfully orienting the map was down to the participants. This study does not intend to suggest that all types of maps are ineffective at boosting orientation, indeed maps which remain oriented with the participant as they move should be effective tools, as shown within previous studies (Darken & Peterson, 2001). The key finding here, matching the results from previous studies, is that without a clear connection between the environment and the symbolised space of the map, participants are unable to effectively match orientation, and unable to gain the potential benefits.

Conclusion

Results indicate that participants recorded lower orientation error within rooms which they had visited during acquisition phases. This suggests that experience of visiting a location previously allowed the participant to more accurately understand the rooms' position within the building environment, reducing recorded error. In addition, it was found that participants were significantly more accurate during orientation trials where they had access to a view of the external environment. It has been proposed that this effect is a consequence of enabling participants to use landmark cues present within the external environment within their local reference frame, facilitating participants' knowledge of where they were within both the local environment of the building and the global environment of the university campus. Overall results suggest that the inclusion of a free to use map did not consistently facilitate interactions. Participants with access to a map of their environment were not consistently more accurate within orientation trials than participants without access to a map. Sjolinder et al. note that the inclusion of a map when using a digital environment should be a carefully considered decision as its inclusion has the potential to downgrade rather than facilitate performance on a variety of metrics, including task efficiency and environmental learning. It can be seen from this study that free standing maps are not sufficient to consistently boost users' ability to orient within virtual environments and that alternative approaches should be taken. Potential alternatives include providing participants with additional orientation cues within the environment.

Experiment 4 – Facilitating orientation via the use of additional orientation cues.

In Experiment 3, it was found that providing participants with a map of their environment was not effective at reducing orientation error within a virtual nested environment. Group Control did not record significantly greater orientation error than Group Map. As a consequence, alternative approaches to facilitating orientation within realistic virtual environments are needed. One potential approach is providing participants with additional cues. From previous research, (Wang & Brockmole, 2003) it is apparent that individuals struggle to maintain orientation within nested environments due to limited visual cues linking their environments. By providing participants with clear visual links between these environments it would be anticipated that orientation difficulty would be reduced. As a consequence, orientation error should also be reduced.

To address this, Experiment 4 investigates whether the inclusion of additional visual cues within a nested virtual environment assists participants' ability to successfully orient. This study followed the same methodological approach as Experiment 3, however, rather than providing a group of participants with a map of the environment, one group of participants were provided with additional colour band orienting cues, designed to help participants track their location within the building. Participants were divided into two groups, Group Control and Group Experimental. Although both groups explored the same environment, colour bands were added to the top of all internal and external walls for Group Experimental (Figures 4.6-4.9).

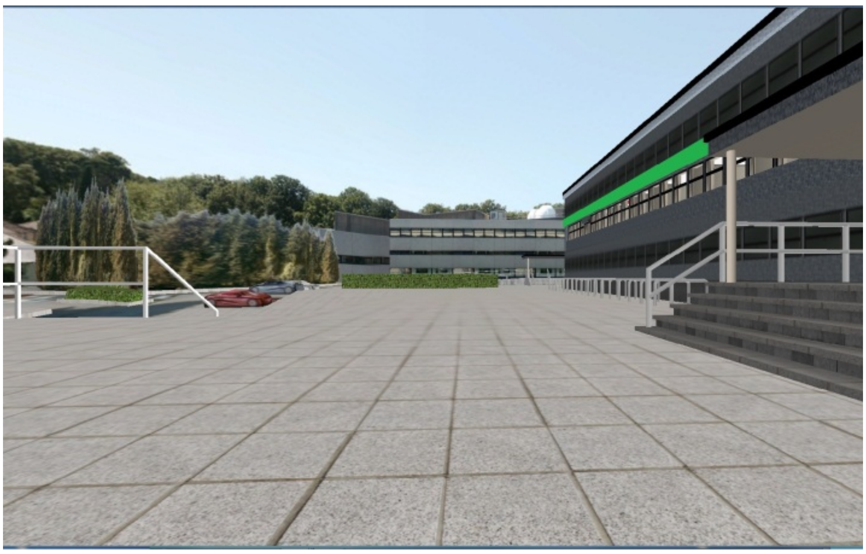


Figure 4.6. View of the external environment during exploration for Group Experimental; note the additional colour band on the building.

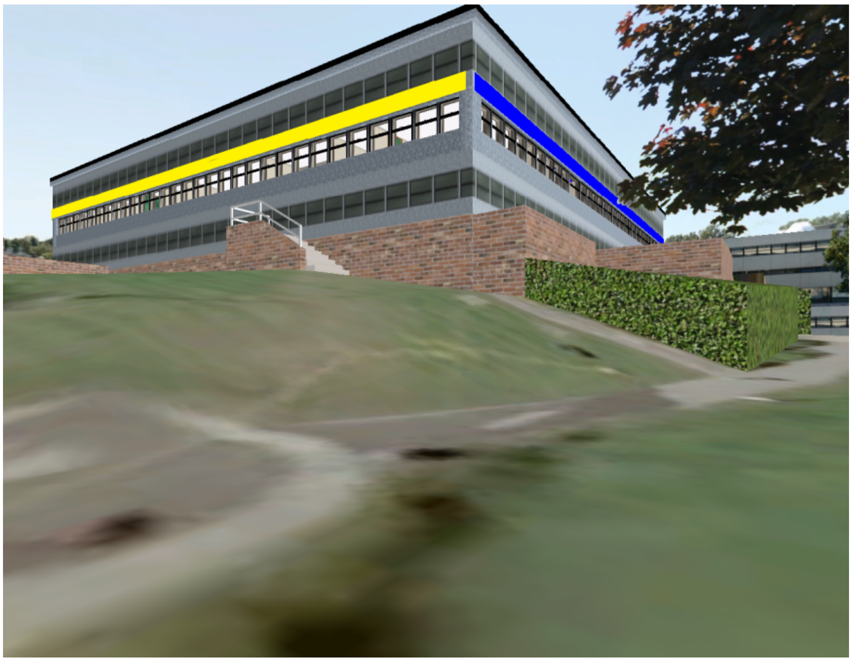


Figure 4.7. View looking at the Shackleton Building from the direction of the Student Union Building, as seen by Group Experimental. Group Control saw the same environment without the colour bands.

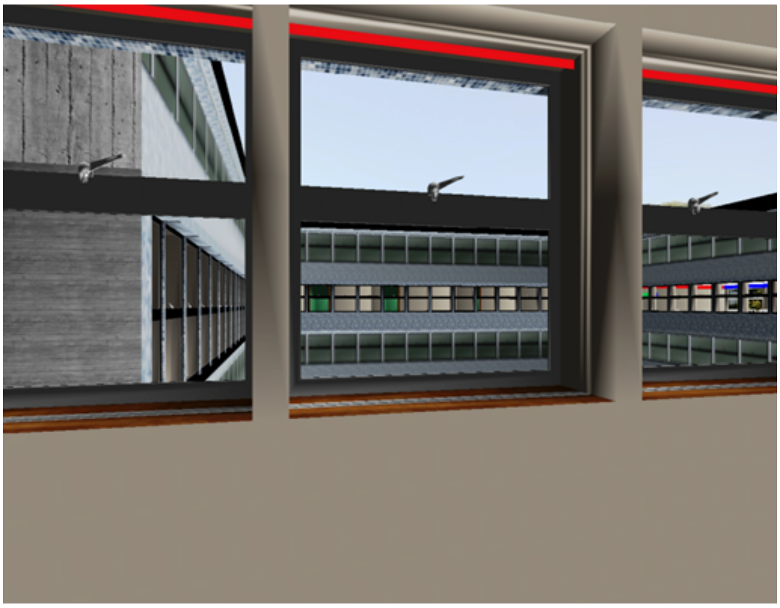


Figure 4.8. View from one of the internal-facing visited trial rooms, as seen by Group Experimental. Although no external landmark cues are available, a red colour band is visible.

Figure 4.9. View from inside the model building seen during exploration for Group Experimental overlooking the car park. The external environment can be clearly seen as well as a green colour band, signifying a link to the car park.

The following study investigated whether individuals' ability to track their overall location in a virtual nested environment could be facilitated by the inclusion of additional cues within the environment. As with Experiment 3, participants explored a virtual nested environment, a model building within a virtual university campus before being required to turn within the model to face a series of non-visible, but previously seen, external targets. In addition to exploring whether colour band orienting cues influenced recorded orientation error, Experiment 4 will also assess the reliability of findings within Experiment 3 regarding the role of a view into the external environment and the importance of experience, visiting a room previously during the acquisition phases. Three key hypotheses were developed based on previous research.

1) Regardless of group, orientation error will be lower within the external-facing, compared to internal-facing, rooms (Wang & Brockmole, 2003).
2) Regardless of group, mean orientation error will be lower in visited, compared to the unvisited, rooms (Riecke, Cunningham & Bulthoff, 2007).
3) Due to the inclusion of additional colour band orienting cues, Group Experimental will record lower mean orientation error than Group Control (Wang & Brockmole, 2003).

Method

Design

This study used a 3-way mixed factorial design. The independent variables were room type (External-facing / Internal-facing), experience (Visited/ Unvisited) [within] and condition (Control/ Experimental) [between]. The dependant variable was orientation error, as measured by pointing accuracy. Participants were randomly allocated between the two conditions.

Participants

Participants were 40 psychology undergraduate students, from the University of Southampton, who completed the study in partial fulfilment of a research participation scheme. Participants were recruited via the use of a departmental recruiting system. Group Control consisted of 8 males and 12 female participants. Group Experimental consisted of 4 males and 16 female participants. Due to the limited age range inherent within the sample, age demographics were not collected. All participants had normal or corrected normal vision. Participants had experience of the real campus, but not of the model. Participants who took part in Experiment 3 were not eligible to participate within this study.

Apparatus and Procedure

The apparatus used in this study was similar to that used in Experiment 3. The study took place in the same windowless research cubicle.

Conditions varied with the number of additional orientation cues provided within the environment. Group Control explored the same virtual model used within Experiment 3 (See Figures 4.1 – 4.3) and were given no additional orientation aids to assist orientation. In contrast, participants within Group Experimental were provided with large colour bands at the top of each wall of the Shackleton building. The bands were of sufficient width so that they could be easily seen by participants as they explored the model (Figure 4.6 – 4.7). The banding was continued within the inside of the model. The colour band cues were arranged so that the external colours matched the colour on the corresponding internal wall. The internal bands were of sufficient width so that they could be easily seen by participants as they explored the interior space (Figures 4.8 – 4.9). The overall layout of the colour bands can be seen within Figure 4.10. Participants were not informed of the group that they had been assigned to and, if appropriate, were not informed about the role or purpose of the colour band cues.

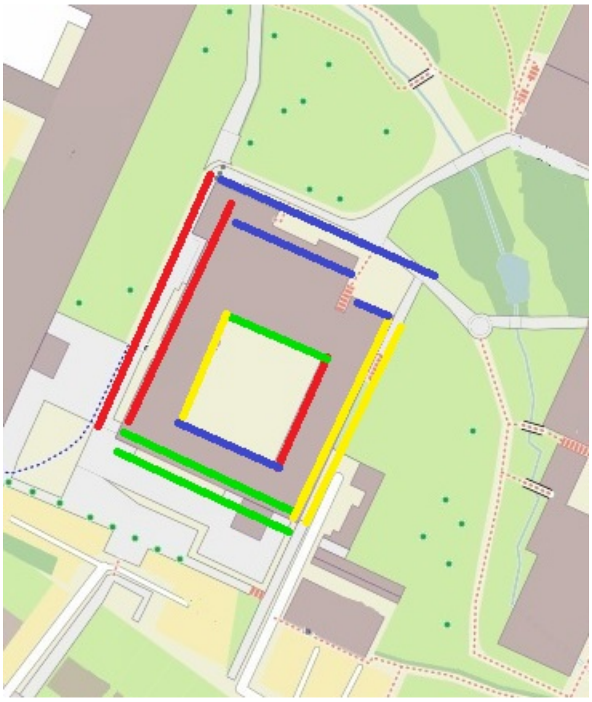


Figure 4.10. The overall layout of the colour band cues for participants within Group Experimental.

Acquisition phases and orientation test trials proceeded as they had within Experiment 3. Participants completed four orientation test trials within rooms classified as Unvisited External-facing, Unvisited Internal-facing, Visited External-facing and Visited Internal-facing.

Results

All statistical tests were evaluated with respect to an alpha value of .05.

Mean orientation error for Group Control and Group Experimental are presented in Figure 4.11. It can be seen from this figure that participants within Group Experimental recorded lower orientation error than Group Control. Although this difference is most apparent within the Internal-facing Unvisited room, it is clear that Group Experimental recorded lower error within three of the four trials. Overall from this figure it is apparent that providing participants with additional orienting cues reduced orientation error. Results for both groups are however consistent with Experiment 3, in that participants recorded lower mean orientation error within external-facing rooms and lower mean orientation error within rooms which had been visited previously during acquisition.

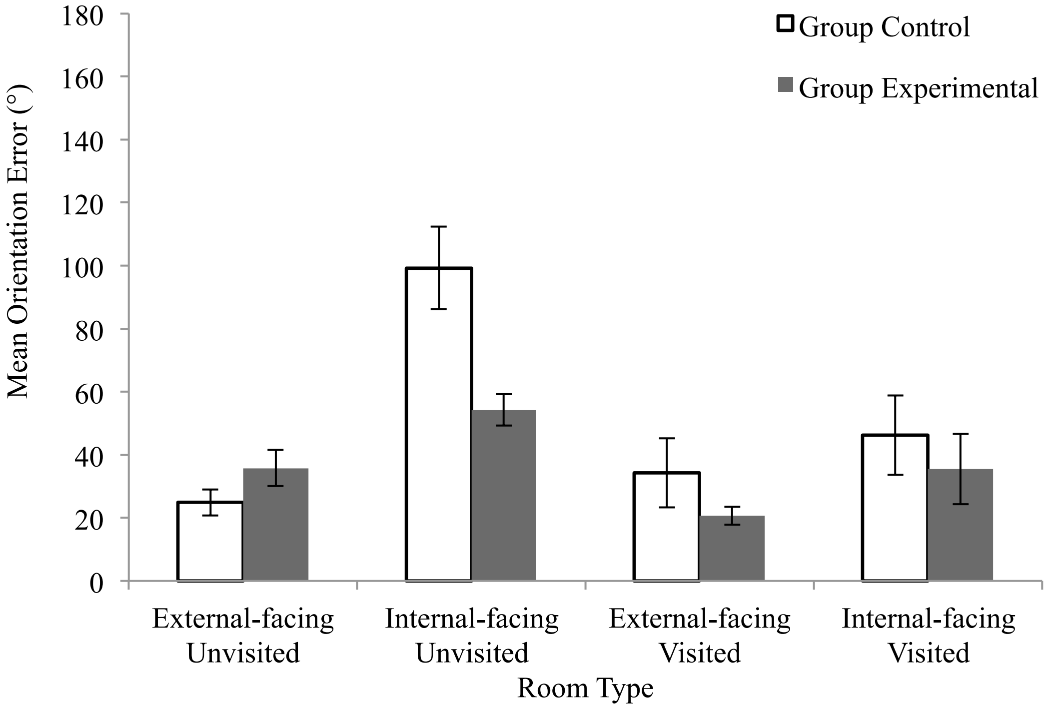


Figure 4.11. Mean orientation error recorded by Group Control and Group Experimental. It can be seen that Group Control recorded higher error than Group Experimental for all bar one of the trials. Furthermore, it is clear that the high error score recorded by participants within Group Control within the internal-facing unvisited room is much reduced for participants within Group Experimental. Error bars represent the estimated standard error of the mean.

To examine the data in more detail, a 3-way mixed design ANOVA was used to explore the effect of room type (Internal-facing / External-facing), experience (Visited/ Unvisited) and condition (Control/ Experimental) on participants' orientation error scores. There was a significant main effect of room type, $F(1, 38) = 5.18$, $p<.05$, $\eta_p^2 = .12$, participants recorded greater error within the internal-facing rooms. There was also a significant main effect of experience, $F(1, 38) = 15.48$, $p<.05$, $\eta_p^2 = .29$, indicating that participants made greater error in rooms which they had not visited during acquisition. A significant effect of condition was also identified, $F(1, 38) = 4.28$, $p<.05$, $\eta_p^2 = .10$. Orientation error in Group Experimental was less than Group Control. A significant interaction was found between room type and experience, $F(1, 38) = 24.24$, $p<.05$, $\eta_p^2 = .39$. The use of simple main effects revealed that there was a significant effect of room type in the unvisited rooms $F(1, 76) = 24.04$, $p<.05$. Regardless of group, participants recorded less error within the external-facing unvisited room than the internal-facing unvisited room. No effect of room type was observed in the visited rooms however, $F(1, 76) = 1.99$, *ns*. This suggests that the presence of an external view made orientation easier, however was not required if the participants had visited the location previously during the acquisition phases. In addition, a significant effect of experience was seen within the internal-facing rooms, *F*(1, 76) = 39.72, $p<.05$. Participants recorded lower orientation error within the internal-facing room that they had visited during acquisition compared to the unvisited internal-facing room. No effect of experience was seen however within the external-facing rooms, *F*(1, 76) = 1.80, *ns*. This suggests that experience of visiting a location previously did not benefit participants when they had a view of the external environment.

A significant 3-way interaction was found between Room Type, Experience and Condition, *F*(1, 38)= 4.78, $p<.05$, $\eta_p^2 = .11$. All other interactions were non-significant (Condition and Experience, *F*<1, *ns,* $\eta_p^2 = .006$; Condition and Room Type, *F*(1, 38) = 4.10, *ns,* $\eta_p^2 = .10$). Further analysis of the 3-way interaction via the use of simple main effects revealed a significant effect of condition in the unvisited, internal-facing room, *F*(1, 152) = 12.38, $p<.05$. Participants within Group Experimental recorded significantly lower error (54.21°) within this room compared to participants within Group Control (99.21°). This result demonstrates that the colour band orienting cues were effective at reducing orientation error within this room. There was however no significant effect of condition within the other rooms (Unvisited External-facing, Visited External-facing *F*s<1, *ns*, Visited Internal-facing *F*(1, 152) = 1.13, *ns*.). That the colour band cues only produced significant improvement within the unvisited internal-facing room indicates that an external view is sufficient to enable satisfactory orientation accuracy, as is visiting a location during acquisition. However, when these cues are unavailable, participants require additional information to make accurate orientation decisions.

Results of this experiment suggest that, consistent with Experiment 3, participants within Group Control struggled to accurately orient within the virtual model, particularly in the internal-facing unvisited room. In contrast, participants within Group Experimental, with access to additional orienting cues recorded significantly lower error. Unlike the inclusion of a map in Experiment 3, the inclusion of the colour band cues reduced orientation error.

Discussion

Results confirmed all hypotheses. It was found that orientation error was lower for all participants within the external-facing rooms, where participants had access to a clear view of the external environment. Orientation error was also lower in rooms that participants visited during the acquisition phases, suggesting that experience facilitated orientation ability. Finally, it was found that the inclusion of the colour band orienting cues within Group Experimental was effective in reducing participants' orientation error. This effect was most apparent within the internal-facing unvisited room, where participants did not have access to an external view and had not visited during acquisition.

The finding that participants' error was greater within the internal-facing rooms suggests that participants were unable to simultaneously update their position within the multiple environments of both the building and the wider campus environment. This is consistent with previous findings, using real world tasks (Wang & Brockmole, 2003). Wang and Brockmole showed that individuals were unable to simultaneously update items within a room and the larger campus following disorientation. They propose that a focus on one environment acts to break the spatial relationships that exist between multiple environments. This is apparent within Experiment 4 from the large errors that Group Control made within the internal-facing rooms. The addition of the colour band cues within Group Experimental, however, allowed participants to orient more effectively, suggesting a greater awareness of their position both within the building and the wider campus environment. Group Experimental did still record higher error within the unvisited internal-facing room than the external-facing rooms but this was not significant. This suggests that although the colour bands were effective at reducing overall orientation error, they were not a perfect replacement for a view of the external environment.

Participant error was higher in rooms that had not been visited previously. This is supportive of research highlighting the role of experience within spatial tasks (Siegel & White, 1975; Nazareth, Herrera & Pruden, 2013; Sakamoto & Spiers, 2014). If participants have had experience of traveling to a location previously during acquisition they are more likely to be able to place the location within an overall cognitive representation of the environment and calculate the rooms position within the wider environmental context, allowing for a more accurate representation. For rooms that had not been visited previously, participants would have been unable to employ this strategy and were therefore reliant on the cues available within the environment. As a consequence, when external environmental cues were lacking, participants record higher orientation error.

The findings that participants recorded higher error within the internal-facing rooms and within the unvisited rooms are highly supportive of Experiment 3, where identical results were seen. Compared to the use of the paper map however the colour band cues were effective at reducing the high orientation error that participants recorded within these rooms. This suggests that the difficulty associated with orienting within virtual nested environments can be reduced if sufficient visual cues are provided.

Conclusion

Experiment 4 aimed to examine the importance of local visual cues when orienting within a virtual space. In addition to replicating the findings of Experiment 3, in terms of effects related to experience and room type, results suggest that losing track of your location within a virtual nested environment can be reduced by the addition of colour band orienting cues. It is hoped that expansion of this research can begin to introduce interventions to reduce disorientation within other nested digital environments.

General Conclusion

Results from Experiment 3 demonstrate that whilst participants could satisfactorily orient within a virtual nested environment when provided with an external view or experience visiting the test room during acquisition, when participants lacked this external-facing view and were placed in an unvisited location they struggled to maintain orientation. This was true even though the environment used was highly familiar to participants. Results from Experiment 3 also demonstrate that access to a freestanding map of the overall environment did not facilitate participants' ability to orient within the virtual model. Results from Experiment 4 demonstrate, however, that participants' ability to orient can be facilitated by the inclusion of salient colour band cues. Participants provided with colour band orienting cues consistently recorded lower orientation error than those without access to these cues. Experiment 7 will examine what properties of the colour band orienting cues help to reduce orientation error, however prior to this, Experiment 5 and Experiment 6 will examine whether active control during acquisition plays a role in participants recorded orientation error. Specifically, Experiment 5 explores whether experience of visiting a location during acquisition remains of benefit when participants are not in control of their movement.

Chapter 5

Passive Spatial Learning

Experiment 5 - The Role of Orienting Cues within Passive Exploration

Results from Experiment 3 and Experiment 4 indicated that participants recorded lower orientation error within rooms which they had visited previous during acquisition. Furthermore, results from Experiment 4 indicated that participants benefited from the addition of colour band orientation cues. Chapter 5 seeks to explore whether direct interaction with the virtual model, active spatial learning, is a prerequisite for participants to benefit from visiting a location previously and the addition of these cues. Specifically, Chapter 3 explores whether participants are able to learn about the environment, and benefit from the colour band orientation cues after watching a pre-recorded tour of the environment, via passive spatial learning.

The view that there are potential differences in the amount of spatial knowledge acquired between active and passive spatial learning is highly intuitive. Maguire, Woollett and Spiers (2006) demonstrated a difference in both the spatial knowledge and hippocampal volume of taxi drivers compared to control participants. Similarly, Appleyard (1970) demonstrated a difference in the spatial knowledge of bus drivers and bus passengers. Although these studies demonstrate differences between active and passive learning, it is difficult to disentangle this from the role of experience, both bus and taxi drives are required to use their spatial knowledge more regularly than control participants and passengers. Demonstrating a causal link between active and passive spatial leaning has therefore been difficult.

The issue is further complicated when considering virtual environments. Within traditional spatial studies, active learning can be viewed as a condition whereby participants are required to physically explore an environment (Thorndyke & Hayes-Roth, 1982; Chrastil & Warren, 2013). These tasks offer participants' idiothetic and vestibular body movement cues (Mittelstaedt & Mittelstaedt, 2001). Although these cues are not available within virtual environments (Hartley, Trinkler & Burgess, 2004), a distinction can be drawn between active and passive learning due to the role of decision making. That is whether participants are actively in control of their movement, as they were within Experiments 3 and 4, or are passive observers. Experiment 5 explores the extent to which participants are able to orient after being passive observers of a tour within the virtual model used previously.

In an early investigation of potential differences between active and passive learning in virtual environments, Peruch, Vercher and Gauthier (1995) investigated whether participants' ability to navigate within an environment differed as a consequence of learning the layout via exploration using a joystick (active), watching a video of the exploration experienced by the active group (passive-dynamic) or after seeing slides of the environment (passive). As would be expected, performance was greatest with active learning, followed by the passive-dynamic followed by passive learning. The findings of Peruch et al. (1995) suggest that as interactivity increases, participants' spatial knowledge also increases. Similarly within a navigation task within a virtual environment, Tan, Gergle, Scupelli and Pausch (2006) found that participants who controlled their movement during acquisition phases travelled shorter distances within test trials than those who watched a passive video of the exploration, suggesting that interactivity aided participants in learning about the environment.

Other studies have however failed to show an advantage for active navigation within virtual environments. Booth, Fisher, Page, Ware and Widen (2000) required participants to explore an abstract virtual environment either as a “passenger” whereby participants witnessed a route but had no control over their movement, or as a “driver” where they were required to use navigation controls to follow the same route as seen by passive participants. Results suggested that passive “passenger” participants were faster at retracing routes than active “driver” participants. Booth et al. note however that a possible explanation for this was the abstract and unfamiliar nature of the environment, which was far from the structured spatial environment of cities and buildings that participants are exposed to on a regular basis. Nevertheless this study suggests that interactivity may not be fundamental to users ability to understand their environment. Wilson, Foreman, Gillett and Stanton (1997) paired participants and asked them to explore a realistic virtual environment before completing a series of orientation trials. Participants were either active or passive at directing travel and either active or passive at controlling their movement during initial exploration. An additional control group with no experience exploring the environment was also included. Results suggested that although all groups with experience of the environment outperformed the control group, there was no difference between active and passive participants. This suggests that experience, rather than interactivity, was the key factor influencing participants’ ability to orient successfully.

From the studies presented, a mixed image is apparent regarding the importance of interactivity. Whilst it seems intuitive that direct experience and control should be of benefit to users, empirical support for this is inconsistent. The following study explores whether the colour band cues, which were used within Experiment 4, impacted participants’ ability to remain oriented when participants did not control their movement, but rather watched a passive tour of the environment. From previous studies and results from Experiment 4, it is anticipated that participants provided with colour band orientating cues should record lower orientation error than participants without these aids. Participants who can see the colour band orientation cues should be able to maintain knowledge of external landmarks within the internal-facing rooms due to clear visual links between the two environments.

Method

Design

This study used a 3-way mixed factorial design. The independent variables were room type (External/ Internal), experience (Visited/ Unvisited), [within] and condition (Control, Experimental) [between]. The dependant variable was whether participants were able to identify the correct orientation direction from a multiple-choice selection. Unlike experiments 1 and 2, the measure within this study was a categorical response, whereby participants were required to choose a wall to face towards labelled A, B, C, or D.

Participants

Participants were 64 University of Southampton undergraduate students. Group Control consisted of 4 male and 22 female participants. Group Experimental consisted of 7 male and 31 female participants. Participants completed this study as part of an activity regarding spatial learning during a behavioural neuroscience tutorial. Participants received no compensation for time spent completing this research study. All participants had experience of the real University campus but had not seen or interacted with the model previously. All participants had normal to corrected normal vision. Due to the limited age range inherent within the sample, age demographics were not collected.

Apparatus

As the key aim of this study was to examine whether interactivity within the model was an essential component of participants' ability to accurately orient, participants did not interact with the virtual model and were instead required to watch a pre-recorded tour of the building. The tours participants saw was dependent on condition. For Group Control, the tours were recorded within the unmodified model, as seen within Experiment 3. Consequently no colour band orienting cues were present within the environment. Participants within Group Experimental saw tours that were recorded within the model as seen by Group Experimental within Experiment 4. Group Experimental therefore saw colour band orienting cues on all external and internal walls of the model. The cues were arranged in the same pattern as used by Group Experimental previously.

Four tours were created for this study, two external acquisition tours, for Group Control and Group Experimental respectively, and two internal acquisition tours, again one for Group Control and one for Group Experimental. Tours were recorded using "Screencast-o-matic", a web hosted screen recorder (Freely available). Tours were matched between groups to ensure that they were as similar as possible to ensure that differences between the tours did not act as a confounding variable. The tours followed the same routes participants' followed during the previous studies to ensure that a route difference was not a factor in participants' orientation performance (See Experiment 3 for detailed descriptions of these routes).

Procedure

Participants completed this study as part of a group tutorial activity. Unlike experiments 3 and 4, this study was a group test conducted in a large lecture theatre, with the virtual environment presented on a large screen at the front of the theatre. Due to the independent design used within this study, different conditions were presented to different tutorial groups. The experimenter explained to participants that the aim of the research was to explore the extent to which individuals were able to track their position within internal spaces. Participants signed a formal consent form prior to completing this study, and were informed by the experimenter that their participation was voluntary.

Prior to the start of the main study, participants were asked to indicate their gender and course of study on a “clicker” response system which recorded each participant’s answers, and provided an opportunity to both ensure participants were familiar with the clicker system, and to allow the experimenter to collect demographic data. Similar to the procedure used previously, the study comprised of two trial phases, acquisition video tour trials and orientation test trials. Participants watched two tours for the acquisition component of the study. Acquisition tours were designed to familiarise participants with the environmental layout. The first acquisition video participants’ watched was an exploration of the external environment. The video shown was dependent on condition. For the second acquisition video tour, participants saw the explorer enter the virtual building and move through level 3 of the building, and into selected rooms. For all participants, the route taken was identical to that used previously within Experiment 3 and Experiment 4. Once participants had been shown both video tours they continued to the orientation test trials.

There were four orientation test trials within this study. Similar to previous studies, participants were digitally placed within rooms within the building and asked to face a non-visible, but before seen, target. Two of the trial rooms had a view overlooking the external campus environment, enabling the use of external landmark cues. Two of the rooms however overlooked the inner courtyard of the building, limiting the available cues. As this study took place during a group tutorial, without access to computer facilities, participants were not able to turn within the model, as such orientation error could not be gathered using the method used previously. Rather, participants were shown a video of two full rotations within the room. On each of the wall was a Letter “A” “B” “C” or “D”. After the video, participants were asked to choose which letter they would face towards so that they were pointing towards the given target. Of the available options, one was correct; one was 90˚ to the left, one 90˚ to the right and one 180˚ away from the correct direction. Participants were required to select their answer using the “clicker” response system that recorded each participant’s answers. The experimenter allowed two minutes for participants to make their orientation decision. Participants were only allowed to make one response per trial. Should participants have attempted to answer multiple times, only the first response would register within the system. The same procedure was used for all four orientation test trials. Once all four orientation test trials had been completed, participants were verbally debriefed by the experimenter and were presented with a debriefing form.

Results

Data Analysis

Participant's responses were collected by the clicker central response system. Participants' alphabetical responses were then converted so that they were assigned an error value of 0˚, 90˚ or 180˚ based on the location of the target and the correct response. Responses were subsequently compared across conditions.

All statistical tests are reported to an alpha value of .05.

Figure 5.1 presents the mean error recorded for each of the orientation test trials for Group Control and Group Experimental. From this figure it is clear that there are limited differences between the groups, other than within the Internal Unvisited room. It appears that the majority of participants were able to effectively orient within rooms with an external view, as demonstrated by the low orientation error recorded within these rooms. Although orientation error increased within the Internal Visited room, this was not a large increase for either group, compared to the external-facing rooms. This suggests that visiting a location previously also assisted participants' ability to orient. Both of these results are consistent with Experiment 4. Orientation error for Group Control within the Internal Unvisited room however was far higher than seen within the other rooms. This can be contrasted with Group Experimental, whose error remained similar to that seen within the other rooms. This suggests that without additional cues, Group Control struggled to accurately orient within a room which they had not visited previously and which lacked an external view. It appears however that the inclusion of the colour band orienting cues facilitated Group Experimental's ability to orient within this room, as demonstrated by a reduction in mean orientation error.

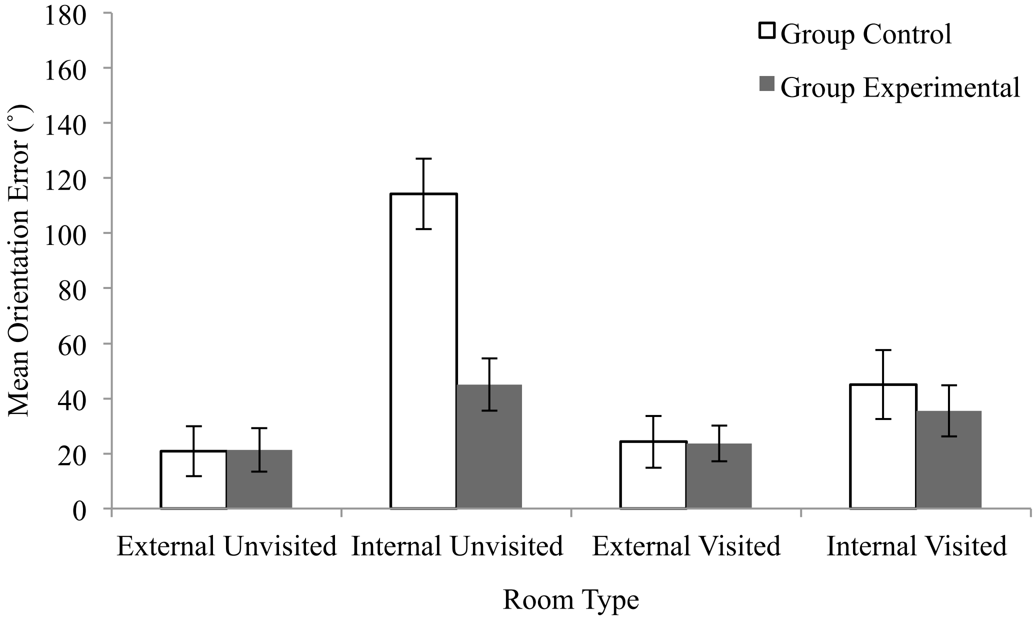


Figure 5.1. Mean orientation error recorded by Group Control and Group Experimental. Other than the internal unvisited room, limited differences can be seen between the two groups. It is clear that the high error recorded by Group Control within the internal unvisited room is much reduced for Group Experimental suggesting that the colour band cues aided orientation. Error bars represent the estimated standard error of the mean.

To examine the data in more detail, a 3-way mixed design analysis of variance (ANOVA) was used to explore the effect of room type (Internal/ External), experience (Visited/ Unvisited) and condition (Control/ Experimental) on participants recorded error scores. There was a significant main effect of room type, $F(1, 62)= 30.75$, $p<.05$, $\eta_p^2 = .33$, participants made greater error within the internal-facing rooms. There was a significant main effect of experience, $F(1, 62)= 5.61, p<.05, \eta_p^2 = .08$, indicating that participants made greater error in rooms which they had not visited during acquisition. A significant effect of condition was also identified, $F(1, 62) = 8.91, p<.05, \eta_p^2 = .13$, Group Experimental recorded significantly reduced orientation error compared to Group Control.

A significant interaction was found between room type and experience, $F(1,62)= 11.67, p<.05, \eta_p^2 = .16$. The use of simple main effects revealed that there was a significant effect of room type in the unvisited rooms $F(1, 124) = 40.90, p<.05$. No effect of room type was observed in the visited rooms however, $F(1, 124) = 3.17$, *ns*. Similar to Experiment 4, the presence of an external view made orientation easier, however was not required if the participants had visited the location previously during the acquisition phases. In addition, a significant effect of experience was seen within the internal-facing rooms, $F(1, 124) = 15.89, p<.05$. Participants recorded lower orientation error within the internal visited room compared to the internal unvisited room. No effect of experience was seen however within the external-facing rooms, $F<1$, *ns*. This suggests that experience of visiting a location previously did not benefit participants when they had a view of the external environment.

A significant 3-way interaction was found between room type, experience and condition, $F(1, 62) = 6.05, p<.05, \eta_p^2 = .09$. Further analysis of the 3-way interaction via the use of simple main effects revealed that a significant effect of condition was seen within the internal unvisited room, $F(1, 248) = 25.70, p<.05$. Participants within Group Experimental recorded significantly lower error within this trial compared to participants within Group Control. This result demonstrates that the colour band orienting cues were effective at reducing orientation error within this room. There was however no significant effect of Condition seen within the other rooms (*F*s<1, *ns*.). That the colour band orienting cues only produced significant improvement within this room indicates that an external view is sufficient to enable satisfactory orientation accuracy, as is visiting a location previously. However, similar to the results seen within Experiment 4, when these cues are unavailable, participants require additional information to make accurate orientation decisions.

Results of this experiment are consistent with Experiment 4. Group Control struggled to accurately orient within the virtual model, particularly within the internal unvisited room. In contrast, Group Experimental, with access to colour band orienting cues recorded significantly lower error. The novel finding within this study is that the colour band cues acted to facilitate participants' ability to orient even after participants watched a passive video tour rather than directly interacting with the model. This suggests that the colour bands are an effective orientation aid and are not reliant on active navigation to influence orientation decisions. Results also demonstrate that experience of a location, visiting it previously during acquisition, remains beneficial to participants even when they were not in control of their movement. Furthermore, it was also clear that a view of the external environment aided participants to accurately orient. This suggests that participants know where they are within the building after witnessing the passive tour rather than actively controlling their movement.

Discussion

Results support the view that participants were able to orient within a passive paradigm. Similar to Experiment 3 and 4, it was found that participants made greater error in the internal-facing rooms, and within the unvisited rooms. It was found however that

Group Experimental, with access to colour band orienting cues, were able to more accurately orient within the internal unvisited room compared to Group Control. Overall results suggest that colour band cues are an effective tool for improving participants' ability to orient within virtual spaces. Results uncovered in this study match those identified within Experiment 4, suggesting that a passive methodology is also a valid tool for investigating participants' ability to orient.

The similarities between the results from this study and those uncovered within Experiment 4 are striking. This suggests that the points raised within the Discussion of Experiment 4 remain valid, for example it appears that participants require a clear visual link between different spatial reference frames, for example the external and internal environments, in order to be able to accurately orient (Wang & Brockmole 2003). When this is lacking, for example within the internal-facing rooms, participants' orientation error increased. This is further magnified if participants lack experience of the room they are in, specifically, the internal unvisited room. The colour band orienting cues however provide a visual link between the otherwise separate aspects of the environment, allowing participants to make clear orienting decisions within novel spaces. As the results of Experiment 4 and Experiment 5 are similar, it is possible to suggest that active control is not required for accurate spatial updating. Rather it appears that visual cues are sufficient to enable accurate spatial updating, counter to the proposals of Reiser, (1989) and Farrell & Robertson (1998). Results indicate that provided the available visual cues offer clear links between the disparate aspects of the environment accurate spatial updating is possible within a virtual environment. With regards to the effect of experience (Visited/ Unvisited) it is clear that this effect is not a response to active movement, but rather due to participants becoming aware of the rooms position within the larger spatial context of the building.

As the results of this experiment are so similar to those uncovered within Experiment 4, it would be tempting to suggest that there is no clear benefit of interactivity, supporting the results of Wilson et al. (1997) and Booth et al. (2000). It however is not possible to make these claims as no direct comparison between active and passive learners was made. No large scale differences are however obvious. One factor, which may contribute to the similarity of the results, is that even though participants within this study did not interact with the model, they still had familiarity with the University of Southampton general campus environment and the Shackleton Building, and as such were not required to learn a novel environment. Familiarity with the environment and pre-exposure may be more important than control within the model. Familiarity with the campus environment may be key for effective orientation. To examine this possibility it would be necessary to repeat the study, recruiting participants unfamiliar with the campus environment.

Conclusion

Results from this study match those found within Experiment 4. Without additional orientation aids, Group Control were unable to accurately orient within the internal unvisited room. Group Experimental, with the additional colour band cues, were however able to more accurately orient and recorded lower error. Overall no clear differences can be seen in the results from this study using passive interactions and Experiment 4, which relied on an active exploration. This study should be repeated however with participants' unfamiliar with the campus to examine whether this is a key factor in allowing participants to successfully orient.

Experiment 6 – Experience and Orientation Accuracy within Passive exploration of a Virtual Building

A just criticism that can be levelled at studies presented thus far is that all participants have had, to some degree, experience of the Shackleton Building and/ or the University of Southampton campus. Previous research (Presson, 1987; Siegel & White, 1975) has argued that substantial familiarity with an environment leads to the development of orientation free survey knowledge. This would suggest that participants familiar with an environment might behave differently to those without familiarity; potentially recording lower orientation error and using environmental cues differently. The current study investigates whether participants unfamiliar with the campus environment are able to orient successfully after witnessing a passive tour. Furthermore, this study aims to investigate whether participants without familiarity can benefit from the inclusion of the colour band orienting cues within the environment. This study follows a similar methodology to Experiment 5, in that participants were divided into Group Control and Group Experimental, and performance across four orientation trials was compared. The novel manipulation within this study is that rather than using undergraduate students familiar with the campus environment, this study examines open day visitors, who are unfamiliar with the campus and Shackleton Building.

Method

Design

This study used a 3-way mixed factorial design. The independent variables were room type (External/ Internal), experience (Visited/ Unvisited), [within] and condition

(Control, Experimental) [between]. The dependant variable was whether participants were able to identify the correct orientation direction from a multiple choice selection.

Participants

Participants were 80 visitors to a series of University of Southampton Academic Unit of Psychology open days. Participants completed this study as part of a research demonstration. Participants received no compensation for time spent completing this research study. Participants had limited experience of the real University campus, completing this study prior to a campus tour and had not seen or interacted with the model previously. All participants had normal to corrected normal vision. Due to a failure of the recording equipment, age and gender demographics were not collected.

Apparatus and Procedure

This study used identical apparatus and procedure as used in Experiment 3. For clarity, participants had not visited any of the rooms that were used as part of this study in the real building, references made to visited and unvisited rooms refer to locations seen within the acquisition phase tours.

Results

Data Analysis

This study used the same data analysis as used previously in Experiment 3.

All statistical tests are reported to an alpha value of .05.

Figure 5.2 presents the mean error recorded for each of the main rooms for both Group Control and Group Experimental. From this figure it is clear that whilst there are limited differences between Group Control and Group Experimental within the external-facing rooms, there does appear to be large differences between the two groups within the internal-facing rooms. It appears that participants within both groups were able to effectively orient within rooms with an external view, as demonstrated by the low orientation error recorded within these rooms. This can be contrasted with the performance of Group Control within the internal-facing rooms, whereby large error was observed. In comparison, Group Experimental recorded consistently low error regardless of room type. This suggests the colour band cues aided Group Experimental to orient within the internal-facing rooms. No clear differences can be seen as a consequence of visiting a location previously; this suggests that unlike previous results, experience of a location is not a factor which influences orientation performance for participants who lack familiarity with the wider campus environment.

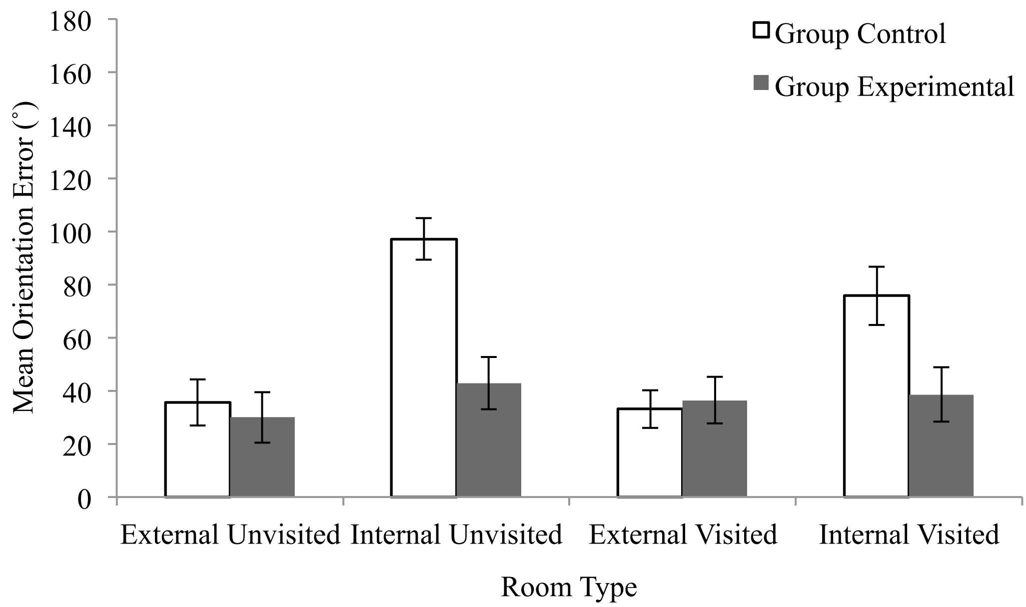


Figure 5.2. Mean orientation error recorded by Group Control and Group Experimental. Although limited differences can be seen between Group Control and Group Experimental within the external-facing rooms, it is clear that within the internal-facing rooms Group Experimental recorded considerably lower error. Error bars represent the estimated standard error of the mean.

To examine the data in more detail, a 3-way mixed design ANOVA was used to explore the effect of room type (Internal/ External), experience (Visited/ Unvisited) and condition (Control/ Experimental) on participants recorded error scores. There was a significant main effect of room type, $F(1,78) = 26.03$, $p<.05$, $\eta_p^2 = .25$, participants made greater error within the internal-facing rooms. A significant effect of condition was also identified, $F(1, 78) = 10.17$, $p<.05$, $\eta_p^2 = .12$, Group Control recorded significantly greater orientation error than Group Experimental. A significant interaction was found between room type and condition, $F(1,78) = 14.58$, $p<.05$, $\eta_p^2 = .16$. The use of simple main effects revealed that there was a significant effect of room type for Group Control, $F(1, 78) = 39.78$, $p<.05$. Group Control orientation error differed as a consequence of being places within an internal or external-facing room. This was not the same for Group Experimental, $F<1$, *ns*. This supported by an effect of condition within the internal-facing rooms, $F(1, 156) = 23.75$, $p<.05$, but not within the external-facing rooms, $F<1$, *ns*. Overall it is clear that Group Control were unable to accurately orient within either of the internal-facing rooms. The inclusion of the colour band orienting cues within Group Experimental however allowed these participants to orient as accurately within both internal-facing rooms as they did within the external-facing rooms.

In contrast to Experiment 5, no significant effect of experience was observed, $F<1$, *ns,* $\eta_p^2 = .01$. This suggests that being able to view the external cues was more important than whether a location had been visited during acquisition.

Results of this experiment are largely consistent with those seen in Experiments 4 and 5. Group Control struggled to accurately orient within the internal-facing rooms. In contrast, Group Experimental, with access to additional orienting cues recorded significantly lower errors within these rooms. The novel finding within this study is that the colour band orienting cues still facilitated participants' ability to orient even when participants had limited familiarity with the university campus environment. This suggests that the colour band orienting cues are an effective orientation aid as they are not reliant on participants' prior knowledge to be effective. It was found, however, that visiting a room previously during acquisition did not help participants orient, no significant differences were seen between the visited and unvisited rooms. This suggests that visiting a location does not help participants orient unless they have a fundamental understanding of the environment.

Discussion

Results from Experiment 6 suggest that participants unfamiliar with the University campus and Shackleton Building can still orient effectively with the addition of the colour band orienting cues. Participants unfamiliar with the campus environment do not however appear to benefit from passively visiting a room during the acquisition trials, as demonstrated by the high recorded error of Group Control within the visited internal-facing room. Participants were able to accurately orient within the model however provided they had a view of the external environment suggesting that relatively short exposure time during the acquisition phases was sufficient to offer a fundamental understanding of the campus environment. The inclusion of the colour band orienting cues within Group Experimental aided participants when they did not have a view of the external environment, significantly reducing orientation error compared to Group Control within the internal-facing rooms.

The key finding in Experiment 6 is the lack of an effect of room level experience for participants unfamiliar with the larger campus environment. One potential explanation for this is that participants lack familiarity with the wider university environment, may focus on the wider spatial context, for example learning the location of the physics building and the location of the car park during acquisition. This is because the external environment comprises of salient landmark cues. Landmark cues are essential in understanding an environment (Siegel & White, 1975; Montello, 1994) and play a central role in remaining oriented (Nash, Edwards, Thompson & Barfield, 2000). Participants unfamiliar with the overall campus environment are therefore likely try to learn the spatial relationships which exists between these landmarks in preference of the internal layout of the building. This can be contrasted to familiar participants who, as they have a fundamental understanding of the environment, learn how different elements within the building relate to the wider campus environment, for example the location of the computer room and its spatial relationship to the car park.

The fact that this effect was not observed in Experiment 5 suggests this finding is a consequence of participants' inexperience of the campus environment rather than a consequence of the passive methodology employed within this study. As the colour band orienting cues aided participants unfamiliar with the environment, questions can be asked regarding how these cues are aiding participants. It may be possible to suggest that Group Experimental are able to form an association between the different colour band cues and external landmark targets, for example the green band and the car park. When participants are aware of this pairing they are not required to learn the exact position of the different elements but rather a series of simple, non-spatial, associations.

What participants are learning about the bands and the exact nature of this association is however currently unknown and will be explored in Experiments in the next chapter. From the current study however it is clear that the colour band orienting cues are an effective tool at reducing orientation error, even when participants lack familiarity with the wider university campus.

Conclusion

Results support the view that the addition of colour band orienting cues can be effective at facilitating participants' ability to orient within a virtual building. Participants who lack familiarity with the campus environment were able to accurately orient within internal-facing rooms when the colour band orienting cues were available. No effect of visiting a location previously however was found suggesting that room level experience is only of benefit once participants have a fundamental understanding of the wider spatial context.

General Conclusion

The effects are generalizable across active and passive media. Results gathered within this chapter using passive trials were highly similar to those uncovered within Experiment 4, where participants had full control of their movement during both acquisition phases and test trials. The addition of the colour band orienting cues for Group Experimental resulted in lower orientation error, particularly within the internal unvisited room. Experiment 4 further expanded on this by investigating whether participants unfamiliar with the campus were able to orient within the virtual model. Again it was found that the addition of the colour band orienting cues within Group Experimental significantly reduced orientation error. It was found however that Group Control did not benefit from experience of visiting a location previously during acquisition phases.

Overall Experiments 5 and 6 add considerable weight to the view that the inclusion of additional orienting cues can facilitate participants' ability to orient within a virtual environment. Why the addition of the colour band orientating cues is so successful, and what participants are learning about these cues however remains unknown and will be explored within Experiment 5. Consistent with Experiments 3 and 4, it was found that participants recorded reduced orientation error within rooms with a view of the external environment. This suggests that a view of the external environment allows participants to place their current location within an overall cognitive representation of the environment, allowing for more accurate responses during the orientation test trials. The effect of experience differed based on participants' overall familiarity with the campus environment. Participants familiar with the campus environment (university undergraduate students) recorded lower orientation error within rooms that had been visited previously during the acquisition phases. Participants who were unfamiliar with the environment (open day visitors) however demonstrated no difference in orientation error based on experience. This finding suggests that participants require a fundamental understanding of the wider environment before they can benefit from experience of benefiting a location during acquisition phases.

Chapter 6

Not all Cues are Equal

Experiment 7 - The Role of Different Cue Configurations on Effective Orientation within a Virtual Nested Environment

It can be seen within previous experiments that the inclusion of colour band orienting cues helped participants to orient within a virtual nested environment. It remains unclear however, why the cues were effective and what aspects of the cues were necessary to facilitate orientation performance. This chapter seeks begin to answer these questions, drawing upon established learning theories to uncover why the bands are effective aids, what aspects of the environment participants are learning about as they explore, and what elements within the environment participants use when they make an orientation decision.

To start to investigate these questions, a study was developed whereby the layout of the colour band orienting cues was changed based on condition. The present study aims to both repeat and expand on Experiment 4, investigating whether the initial salience of the cues or the nature of their layout was fundamental to their effectiveness. As part of this study, it was necessary to replicate the findings of Experiment 4. Consequently, a control group and experimental group were once again included. These conditions were unchanged from those used previously in Experiment 4. Participants assigned to Group Control had no colour band cues added to the environment (See Figure 6.1) Group Experimental in contrast, had access to the colour bands orienting cues on both the outside and inside of the building model. The bands were organised as they had been previously within Experiment 4, for the external walls, the northern facing wall had a green band, eastern wall red, southern blue and western yellow. The bands were of sufficient width so that they could be easily seen by participants. The internal bands matched the colour on the corresponding external wall. As a result, all northern facing walls had a blue band, east walls yellow, southern green and western red. This formed an associative pattern. To illustrate this, if a participant looked towards the building whist standing within the car park (part of the external environment) they would see a green band on the outside of the building. When the participant was in the building (the internal environment) and they were to look in the direction of the car park, they would also see a green band (See Figure 2.10).

Figure 6.1. For Group Control no additional colour bands were added to the environment. Participants therefore had to rely on standard environmental cues.

For Group Directional, the first novel condition which was added to this study, the layout of the colour band orienting cues were changed so that they were based on the cardinal direction the wall was facing. This can be seen as a contrast to the layout used in Group Experimental, whereby the bands indicated the location of an external landmark target, for example green bands indicated the direction of the car park. The bands seen by Group Directional indicate cardinal direction; consequently green bands were placed on all southern facing walls, for both the exterior and interior of the building. This group was added to examine whether the associative nature of the colour band orientation cues presented to Group Experimental was essential in facilitating orientation or whether participants were simply learning a relationship between the cues and the wider environment. Previous research has proposed a distinction between two possible modes of reasoning, reasoning which can be thought of as an associative system and reasoning which occurs as a consequence of a rule based system (Sloman, 1996). Sloman argues that *"The associative system encodes and processes statistical regularities of its environment, frequencies and correlations amongst the various features of the world. For example, a symmetric association between two features can be interpreted as a kind of correlation between those features."* (Sloman 1996, *p*4). Sloman highlights that the association between features can be seen as the probability of a feature given the presence of the other feature, for example the probability of rain given dark clouds. Within the current study, this association can be seen within Group Experimental, when a participant sees a green band they are either within the car park or looking towards the car park. In contrast to associative reasoning which is based on temporal congruency, rule based reasoning is productive and systematic (Sloman, 1996), meaning that rules are based on an unlimited number of learnt rules, for example it is always possible to generate a larger number by adding one to a previous number and that a potential to learn rules means that participants can also learn different rules. Rule based processing requires the learner to engage in reasoning regarding the relationship between two or more variables (Sloman, 1996). Group Directional must learn that the colour bands indicate a cardinal direction and cannot learn a simple association.

Group Directional do not see consistent colour bands between landmarks, but rather the potentially more abstract relationship of cardinal direction and colour bands, a relationship that may not be immediately apparent. Participants are never made explicitly aware that the colour bands are arranged in a cardinal pattern. Because of this, participants are required to identify that the colour bands are designed as an orientation aid, before learning that the bands point to a cardinal direction. To complete this task, participants must learn an abstract cue pattern rather than identify a cue and landmark contingency, participants cannot simply associate the car park with the green colour band cue. In comparison to Group Experimental, Group Directional must engage in controlled rule based processing and cannot rely on a simple associative contingency. When participants are exploring the model building, they may have insufficient time to develop sufficient understanding, especially considering the presence of the external landmark cues during acquisition, which may compete with the colour band cues. Previous research has indicated that potential causes of an event can compete for causal status (Beckers, De Houwer, Pineno, & Miller, 2005), such that, the predictive value of a cue is not only based on the presence of that cue, but also influenced by other cues which co-occur, within the current exploration, the colour bands and the external landmark cues. Consequently, due to the complexity of the task, it would be predicted that Group Directional will record higher orientation error than participants within Group Experimental. It would however be anticipated that the presence of colour band cues which can be used to facilitate orientation will result in lower error than Group Control. The layout of the colour bands for participants within Group Directional is illustrated in Figure 6.2.

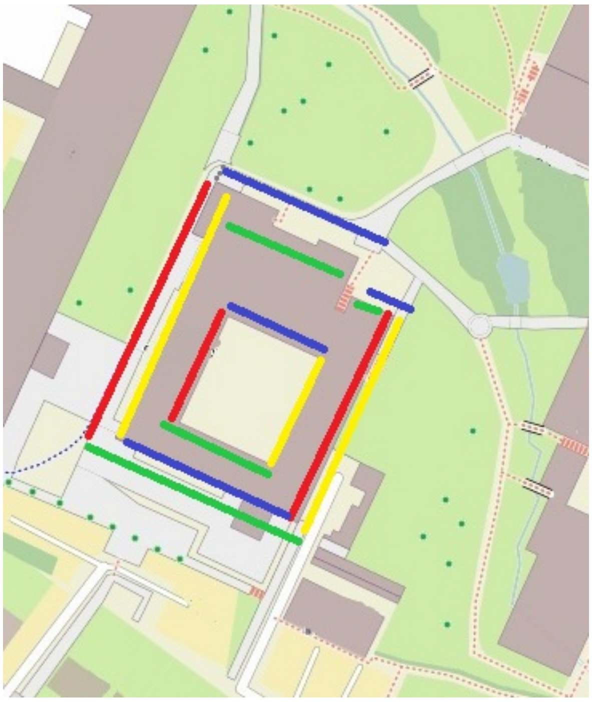


Figure 6.2. Participants within Group Directional had access to colour band cues on both the inside and outside of the building. Unlike Group Experimental however these were arranged based on the cardinal direction of the walls facing.

The second novel condition added to this study was Group Internal. For Group Internal, the colour band orienting cues were removed from the outside of the building; however were still present within the building, using the same layout as used previously for Group Experimental (See Figure 6.3). This adaptation meant that Group Internal could not see any colour band orienting cues on the outside of the building during the first acquisition phase, however the cues were present during the second acquisition phase and the orientation test trials. This condition therefore investigated whether the presence of the colour band cues during the initial acquisition phase was essential for participants to form an association between the colour band orienting cues and the external landmarks. If this is essential, Group Internal would be expected to record higher orientation error than Group Experimental. By presenting the colour band orienting cues inside the building only, it is possible that the bands will have lower visual saliency than if they are presented from the first trial. Previous research has indicated that both the unconditioned response and the rate of learning regarding a stimulus are related to saliency (Hall, 1994). Folk, Remington and Johnston, (1992) suggest that stimulus is more likely to attract attention if it is highly salient. Participants are still offered the opportunity to pair the internal cues to external landmarks however, so may still be able to use the colour band orienting cues when other cues are not available. The presence of the bands should therefore still be sufficient to support orientation performance. Consequently, Group Internal would still be anticipated to record lower orientation error than Group Control, albeit greater orientation error than Group Experimental.

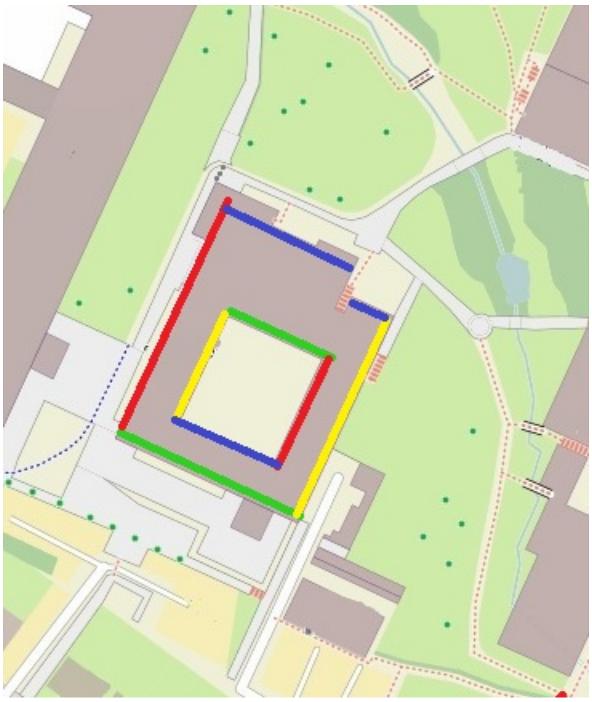


Figure 6.3. Participants within Group Internal had access to colour band cues on the inside of the building only. Participants still however had opportunity to learn

the layout of the colour bands and potentially learn associations between the bands and external landmarks within the second acquisition phase.

Based on Experiment 4, the following hypotheses can be suggested

1) Results will replicate Experiment 4, with Group Experimental recording lower mean orientation error than Group Control. Regardless of group however, participants will record lower mean orientation error within external-facing rooms (Wang & Brockmole, 2003) and lower mean orientation error within rooms visited previously (Riecke, Cunningham & Bulthoff, 2007).
2) Participants with access to colour band orienting cues (Group Experimental, Group Directional and Group Internal) will record lower mean orientation error than Group Control (Experiments 4, 5 & 6).
3) Mean orientation error will differ across the four conditions (Experimental, Directional, Internal and Control). Based on cue saliency (Hall, 1994) and the ability to form a simple association between the colour band orienting cues (Sloman, 1996), Group Experimental will record lowest mean orientation error. Due to the lack of additional cues, Group Control is anticipated to record greatest mean orientation error. Group Directional and Group Internal are anticipated to perform better than Group Control, however not as well as Group Experimental.

Method

Design

This study used a 3-way mixed factorial design. The independent variables were room type (External-facing / Internal-facing), experience (Visited/ Unvisited), [within] and condition (Control/ Experimental/ Internal/ Directional) [between]. The dependant variable was orientation error, as measured by pointing accuracy across the four trial rooms. Participants were randomly allocated to the different conditions.

Participants

Participants were 153 University of Southampton undergraduate psychology students. Participants were offered credit towards a research participation scheme in compensation for the time spent completing this research study. Participants were randomly assigned to one of the four conditions. All participants had experience of the real Shackleton building and University campus but did not have experience of the model. All participants had normal or corrected to normal vision. Due to the limited age range inherent within the sample, age demographics were not collected. Participants within this study had not participated in any of the experiments presented previously.

Apparatus

The basic virtual environment that participants interacted with was unchanged from Experiment 3. See Experiment 3 for these details and an outline of the study apparatus.

Conditions varied based on the orientating cues that were added to the virtual environment. Participants within Group Control and Group Experimental received the same stimuli as Group Control and Group Experimental in Experiment 4. Group Internal were provided with additional colour band cues at the top of each of the internal walls only. The internal colour bands however matched those seen by Group Experimental. As the cues were not visible from the outside of the building, participants could only see these cues within the second acquisition phase and during the orientation test trials. Participants within Group Directional had access to colour band cues on both the outside and inside of the virtual building model. Cues were arranged so that they conveyed the direction the wall was facing, for example all south facing walls had a green colour band, and all north facing walls had a blue band added. As these cues were available on both the outside and the inside of the building, they were visible from the start of the first acquisition phase. For further clarification regarding the layout of the colour cues, please refer to Figure 4.1 – 4.4 which present simplified maps of the environment and the layout of the colour band cues within the different conditions. To ensure fair comparison between groups, the colour band cues were all identical width, positioned in the same locations and were of sufficient size so that they could be easily seen by participants. Participants were not informed of the different groups within the study and, if appropriate, were not informed of the colour bands, the patterns the bands formed or their potential benefit as orientation aids.

Procedure

Other than the additional groups within this study, the procedure used was identical to that used previously; see Experiment 3 for a detailed summary.

Results

All statistical tests were evaluated with respect to an alpha value of .05.

Mean orientation error for each room for the four groups, Control, Experimental, Internal and Directional across each of the four trial rooms are presented within Figure 6.4. Figure 6.5 presents the overall mean orientation error scores for each condition. From these figures it appears that Group Experimental recorded the lowest orientation error. It was found that across the four trials, Group Control recorded a mean of 37° greater orientation error than Group Experimental. This is consistent with Experiment 4, which demonstrated that the colour band orienting cues are effective in reducing orientation error. Group Control, with no additional orientation aids consistently recorded high error across the four trials. Group Directional recorded higher orientation error than Group Experimental for three of the four trials, and performed worse than Group Control, recording higher orientation error. This finding would suggest that directional cues are not effective as an orientation aid. Similarly, Group Internal performed only marginally better than Group Control (Figure 6.5). Furthermore, Group Internal recorded the highest error within the unvisited external-facing room, suggesting that the internal cues did not consistently improve participants' ability to orient. Overall, from these figures it appears that original layout of the colour band orienting cues, which aimed to facilitate an association between a colour and an external landmark, consistently improved participants' ability to orient to a greater extent than the directional cues and internal only cues.

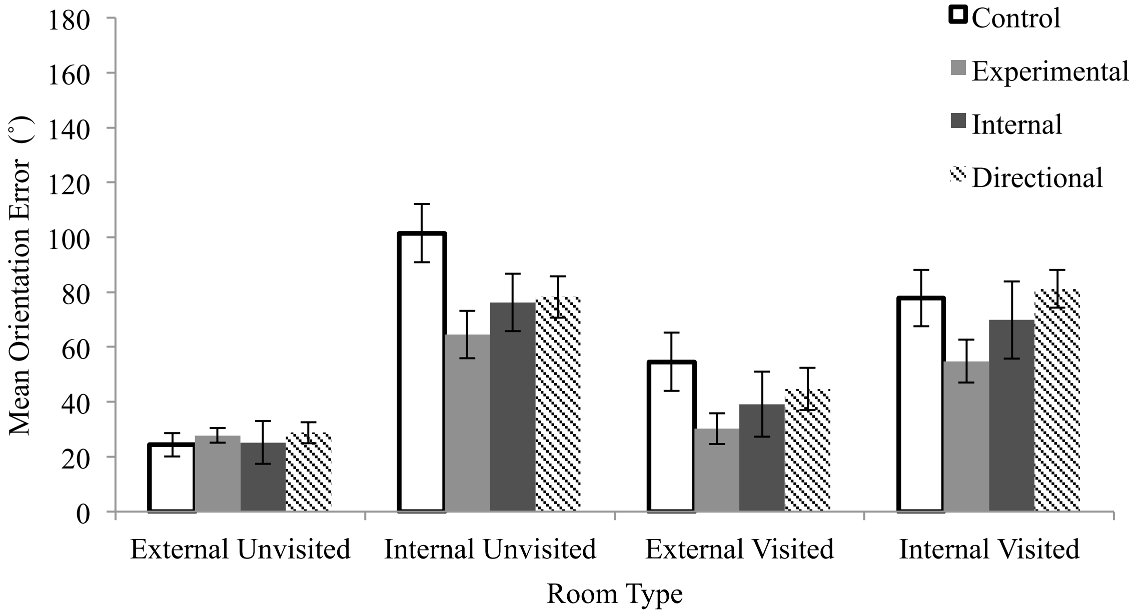


Figure 6.4. Participants mean orientation error for each of the four conditions. It can be seen that participants within Group Experimental consistently recorded low error (were more accurate) compared the other groups. Error bars represent the estimated standard error of the mean.

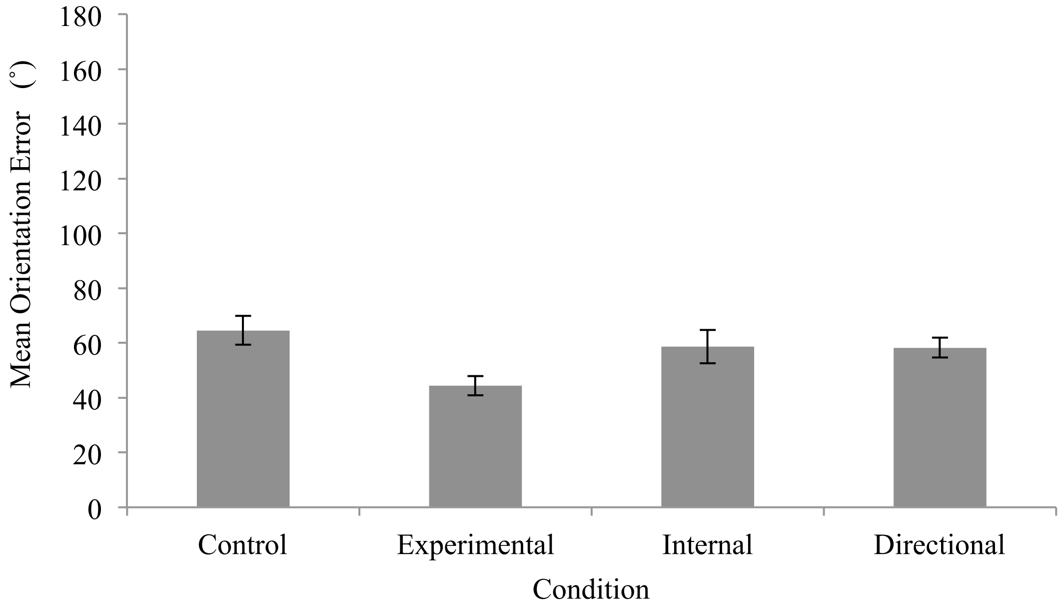


Figure 6.5. Total mean orientation error for each of the four conditions. It can be seen that Group Experimental recorded lowest mean error with neither Group Internal nor Group Directional appearing to differ from Group Control. Error bars represent the estimated standard error of the mean.

A 2 X 2 X 4 mixed design ANOVA was used to explore the effect of room type (Internal-facing / External-facing), experience (Visited/ Unvisited), and condition (Control/ Experimental/ Internal/ Directional) on participants' orientation error. A significant effect of room type was observed, $F(1, 149) = 84.14$, $p<.05$, $\eta_p^2 = .36$. Participants recorded significantly lower orientation error within the external-facing rooms. No main effect of experience was observed within this study, $F<1$, *ns*, suggesting that the experience of visiting a location previously did not significantly influence participants' subsequent orientation error. A significant effect of condition was however identified, $F(3, 149) = 2.69$, $p<.05$, $\eta_p^2 = .06$. To explore this effect in more detail, Bonferroni post hoc analysis revealed that Group Experimental recorded significantly lower error than Group Control ($p<.05$). All other conditions comparisons were non-significant.

A significant interaction of room type and experience was found, $F(1, 149) = 20.53$, $p<.05$, $\eta_p^2 = .12$. Consistent with Experiments 1 and 2, participants recorded the highest orientation error within the unvisited internal-facing room. Simple main effects analysis revealed there was an effect of Room Type for both unvisited ($F(1, 298) = 96.66$, $p< .05$) and visited ($F(1, 298) = 13.90$, $p< .05$) rooms. This suggests that participants recorded greater error within the internal-facing rooms compared to external-facing rooms. Furthermore, an effect of experience was found in the internal-facing rooms ($F(1,298) = 14.24$, $p< .05$), participants recorded lower error within the internal-facing room which they had visited previously during acquisition. An effect of experience was also found within the external-facing rooms ($F(1, 298) = 8.05$, $p< .05$), however, unlike the internal-facing rooms, participants recorded greater error within the visited, compared to the unvisited external-facing room. Although this finding was not expected, upon examination of means recorded within previous experiments, it is seen that participants, especially within Group Control, record a slightly higher mean than would be anticipated within this room. It is suggested that this is a consequence of the rooms used within these studies and the layout of the campus environment, as the External-facing Unvisited room overlooks the Physics Building, the first and last landmark participants would see, whereas the External-facing Visited room overlooked the main campus, which has less salient landmarks. This suggests that there could be a primacy/ recency effect (Murdock, 1962) influencing participant’s ability to orient. An alternative approach is to consider that different elements of the surrounding external environment, based on the real university campus, differ in terms of cue saliency. It may be that the physics building as it is considerably closer to the Shackleton building than either the student union building or the main campus is considerably more salient, influencing participants' ability to orient. Further work exploring alternative test trial rooms or alternative acquisition routes would be required which was not possible within the current research.

Returning to the current results, a significant interaction between experience and condition was observed $F(3, 149) = 2.87, p<.05, \eta_p^2 = .05$. Simple main effects analysis demonstrated that there was a significant effect of experience for Group Internal $F(1, 149) = 6.90, p<.05$, but not for any other groups. Group Internal recorded significantly greater mean orientation error within unvisited rooms (Mean Orientation Error = 68.15˚) compared to visited rooms (Mean Orientation Error = 49.15˚). This suggests that the internal only cues did not facilitate participants' ability to orient within novel locations.

A significant 3-way interaction was observed between Room Type, Experience and Condition, $F(3, 149) = 2.83, p< .05, \eta_p^2 = .05$. Simple main effects analysis revealed that there was a significant effect of condition within the unvisited internal-facing room $F(3, 596) = 4.24, p<.05$. Additionally, a significant effect of condition was seen within the visited internal-facing room $F(3, 596) = 3.46, p<.05$. Post hoc comparisons using Bonferroni analysis however demonstrated that there was only a significant difference between Group Experimental and Group Control within the unvisited internal-facing room ($p<.05$), with all other comparisons failing to reach statistical significance. These findings suggest that the groups did not significantly differ within the external-facing rooms and when participants had visited a location previously, but did differ within internal-facing rooms that participants had not visited during acquisition.

Overall, results suggest that associative cues presented to Group Experimental are the most effective tool for improving orientation within a realistic digital nested environment. Group Experimental consistently recorded low orientation error across the four trials. This was significantly different from Group Control. In contrast, the other manipulations, directional cues and internal only cues, failed to significantly reduce participants' orientation error compared to Group Control.

Discussion

This experiment examined the role of a variety of cue arrangement in reducing orientation error within a virtual nested environment. Results suggest that the colour band orientation cues are only effective at reducing orientation error for Group Experimental when participants are able to form an association between the colour band and an external target, for example the green band and the car park. This learnt association allowed participants to accurately track their relative heading whilst within the building, even within unfamiliar locations. The performance of Group Internal suggests however that it essential that the colour band orienting cues be present on the outside of the building and available from the initial trial. Participants within Group Internal were unable to form an association between the colour band orienting cues within the building model and the external environment, consequently recording high error scores. Extending this view, participants within Group Directional did not appear able to develop clear knowledge of the colour band cues, as such could not use the cues to facilitate performance, recording high error. Overall, it appears that associative colour bands, as used by Group Experimental are the most effect form of orientation cues.

Two potential reasons can be put forward to help explain the effectiveness of the associative cues, firstly the saliency of these cues and secondly the simplicity of the learnt association. In terms of saliency, it has been argued that both the size of the unconditioned response and the rate of learning regarding a stimulus are related to its intensity (Hall, 1994). A stimulus is more likely to attract attention if it is highly salient, for example as a result of perceptual properties, such as a large size or bright colours (Folk, Remington & Johnston, 1992). Furthermore, research by Le Pelley and McLaran (2003) demonstrated that if a stimulus is highly predictive of an event it is also likely to be attended to more. Within the present study, for Group Experimental, seeing the colour bands immediately upon first exposure to the environment would have made them highly salient. Subsequently, the learnt associative pattern would have been reinforced during the second acquisition phase. During this trial, participants would have already been aware of the colour band orienting cues within the environment and consequently their appearance on the inside of the building may have attracted more attention as participants became aware of the cues potential value in predicting their overall position within the model. This can be directly compared to Group Internal. As the bands only appeared on the inside of the building, they may not have appeared as salient, participants would have already become accomplished at using environmental cues, consequently the internal only bands were likely to be of less perceived value. With lower saliency and no opportunity for learning regarding the colour band cues to be reinforced, Group Internal was unable to effectively use these cues. As such, despite having access to identical cues as Group Experimental within the orientation test trials, Group Internal recorded higher mean error.

A saliency based explanation cannot, however, account for the poor performance of Group Directional. Within this condition the colour band cues were available from the first acquisition phase, as they were for Group Experimental. Despite this, these cues did not significantly reduce participants' orientation error. This suggests that participants' requirement to understand the directional relationship of the cues is more difficult to learn than a simple association. It appears that Group Directional failed to engage in rule based reasoning regarding the cues (Sloman, 1996); consequently failing to learn a clear relationship between the cues and the external environment. As participants were not aware of this relationship, they were unable to effectively use the colour band orienting cues during the orientation test trials.

One area, which has not been addressed within this study, is the extent to which participants are using the different cues that are available to them. When participants make an orientation decision, are they solely reliant on the colour band orienting cues or are they using alternative cues which are available? For example, within the external-facing rooms, are participants using the external landmark cues or the colour band orienting cues? The significantly lower mean error recorded by Group Experimental compared to Group Control, suggests that Group Experimental were using the colour band orienting cues instead of the alternative cues which are available. It has been proposed that Group Experimental record lower orientation error as they are able to learn a simple association between two stimuli, a colour band cue and an external landmark, for example learning that the green band equates to the direction of the car park. The development of this association should follow an associative process. As cues compete for associative strength, participants may develop a clear preference for using one type of cue, for example exclusively using the colour bands in exclusion of the external landmark cues. Experiment 8 will investigate this possibility.

Conclusion

Overall results from this study show that the associative cues reduced participants' orientation error by a significantly greater extent than directional cues and internal only cues. When compared to Group Control, with no access to additional orienting cues, it is clear that the associative cues provided consistent facilitation to performance.

Furthermore, Group Experimental recorded lower mean error than both Group Internal and Group Directional. Further work is needed however to explore to what extent participants are using the different cues available to them, and whether use of the colour cues disrupts participants ability to orient without them.

Experiment 8 – Investigating Cue Preference within a Virtual Building

From the results of Experiments 4 - 7, it appears that participants within Group Experimental are able to use colour band orientation cues to effectively orient within a virtual building. This suggests that participants are forming an association between the colour band cues and external landmark targets. For example, participants are learning that the green band is associated with the car park. Participants also appear to be able to form associations between the different external cues, for example the car park and the physics building. Experiment 8 explores which cues participants are using when making an orientation decision, the external cues or the colour band cues, and whether both can be used equally.

As participants explore the virtual building model, they are learning information about the environment and the different cues that are available, for example the colour band cues and items within the external environment that could be used as landmark cues. As participants are exposed to multiple different cue types it is possible that they develop a preference for one of the cue types, using it exclusively. For example, once participants are aware that the colour band cues can be used to accurately estimate the location of external targets, they do not need to consider the external landmarks. Equally due to their familiarity with the campus, participants may prefer to use the external landmark cues in preference to the colour band cues should the opportunity become available.

Based on this potential disparity in cue preference, it is important to ask whether, when exploring a digital environment whereby both external landmark cues and colour band orienting cues are available, are participants able to use both cue types equally well or does the presence of one type of cue disrupt learning regarding the other. The performance of Group Control from Experiments 4 - 7 in the external-facing rooms suggests that participants are able to form an association between one external landmark cue and the non-visible target. The performance of Group Experimental in the internal-facing rooms suggests that participants have formed an association between the colour band orienting cues and the target. During training however, Group Experimental were exposed to both cues, the aim of the present experiment is to examine which association is stronger, external landmark cues and target or colour band orienting cues and target. As the colour band orienting cues are always available within the environment, compared to landmark cues which are only available when participants have a clear view in the corresponding direction of the landmark, it would be anticipated that participants will display a preference for using the colour band cues. To examine this, it is necessary to train participants with both cue types available then test them with:-

i) Both cues types
ii) External landmark cues only
iii) Colour band orienting cues only

Should participants' be able to use both cue types equally well, no differences would be anticipated between these trials. If one cue type is preferred, orientation error will be significantly higher when the former is not available.

Behaviour within these trials will make it clear the extent to which participants are able to use the colour band and external landmark cues. What will not be apparent is the interaction between these cues. It may be that in the absence of the colour band cues participants are able to use the external cues, however are the external cues used when the colour band cues are available? When given the choice to use either external cues or the colour band cues which do participants choose?

One way of testing this would be the use of a contrast trial, as used by Redhead, Hamilton, Parker, Chang and Allison (2013), where the cues provide contradictory information. Cues can be organised so that they directly compete, identifying different locations as the target position. Within the current study, participants could be placed within a room overlooking the Student Union building, meaning the car park is to the right; however a green band can be placed on the wall to the left. Should participants use the external cues they will turn to their right, however if they are reliant on the colour band cues they will turn to their left, dramatically increasing recorded orientation error. Within the contrast trial, it can be seen which of the cue types takes precedence for participants. Indeed it may be that participants are proficient at using both external landmark cues and colour band orienting cues within the cue proficiency trials but would prefer to use one type of cue when given the option.

To summarise the current study, participants will be asked to explore a digital model of a building. During exploration participants will see both external landmark cues and colour band cues within the model. During the acquisition stage, both of these elements will be presented in compound. During the orientation trials, participants will be asked to use these different elements, both in compound and individually (See Figures 6.6 – 6.8) to determine the direction of different targets within the environment. Participants would have seen the targets previously as they explored the environment but could not see the target during the orientation trials. Participants' ability to accurately determine the target location will be measured. If participants' ability to orient within the trials differ, it will be possible to conclude that participants are more able to use one type of cue. Within the Contrast trial (Figure 6.9), the standard colour cues will be altered to be opposite of the learnt configuration. Within this trial it will be possible to determine which cue type participants use when given opportunity to use both, if participants use the external landmark cues no difference should be expected between this trial and the control trial, should participants use the colour band cues however it would be expected that participants will record high error scores.

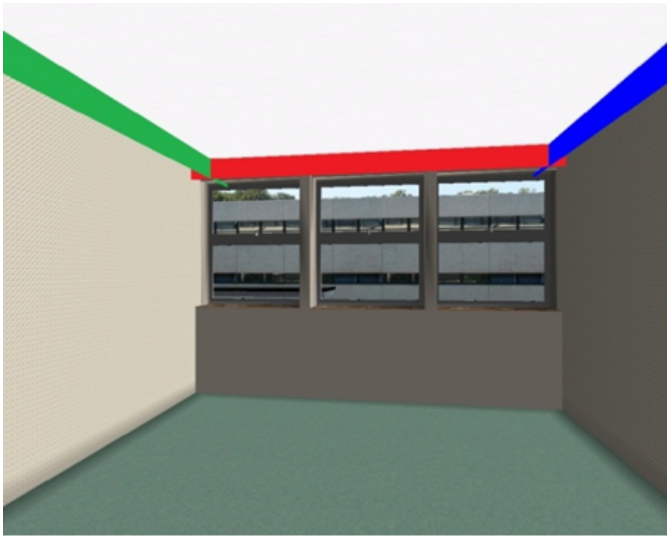


Figure 6.6. Control trial view. Participants had access to both the colour band cues and a clear view of the external environment, both of which could be used within this trial.

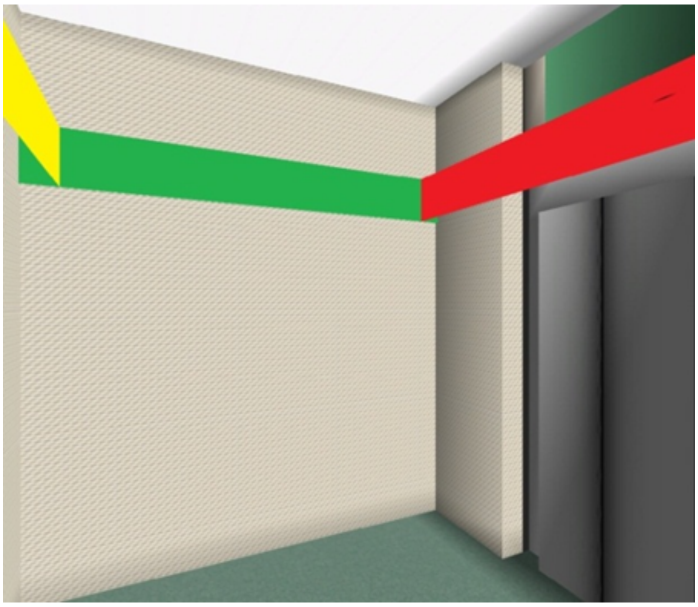


Figure 6.7. View of the colour band orienting cues only trial. Participants only had access to the colour band orienting cues. No external cues were available within this trial.

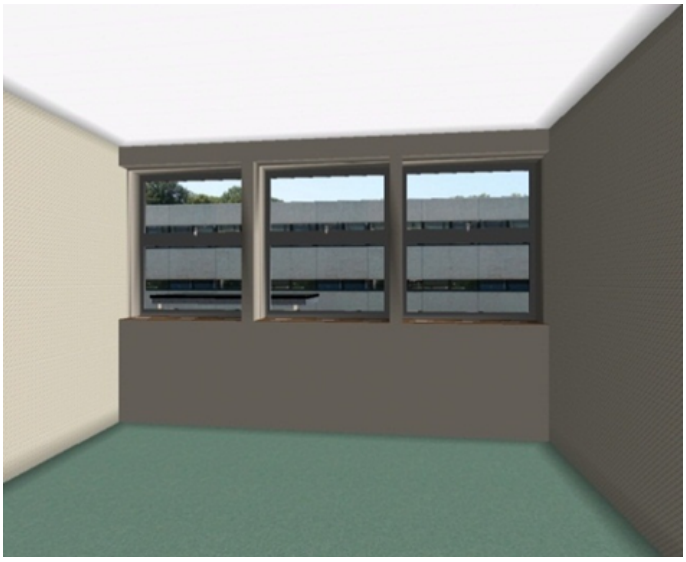


Figure 6.8. View participants saw during the external only trial. Note there are no colour band cues present.

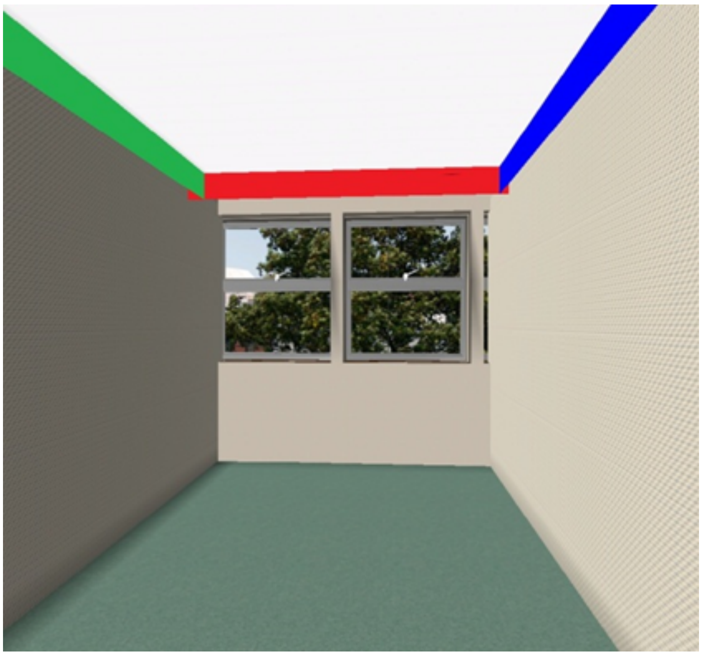


Figure 6.9. View during the contrast trial. The colour band cues are inverted compared to both acquisition phases and the other orientation test trials. Consequently, participants who use these cues will record significantly greater error than they would within the other trials.

Based on previous research, both from previous findings within this research programme, the following hypotheses can be suggested:-

1) Participants' orientation accuracy within the Control trial (external landmark cues and colour band cues) will differ from participants' accuracy within the external landmark cue only trial and the colour band cue only trial.
2) Participants' will record higher orientation error within the Contrast trial than the Control trial if the colour band orienting cues disrupt learning regarding the external landmark cues.

Method

Design

This study used a 4 x 2 mixed factorial design. Independent variables were the cues available within the orientation trials, Control (External landmark cues and colour band cues available), Colour band cues only, External landmark cues only and Contrast (External landmark cues and inverted colour band cues), and group (Counterbalance 1 or Counterbalance 2). The dependant variable was recorded orientation error.

Participants

Participants were 28 undergraduate students from the University of Southampton who completed the study in exchange for credit towards a research participation scheme. Participants were randomly assigned between Group Counterbalance 1 (CB1) and Group Counterbalance 2 (CB2). Group CB1 contained 4 male and 10 female participants and Group CB2 contained 3 males and 11 females. All participants had experience of the real Shackleton building and university campus but not have experience of the model. All participants had normal to corrected normal vision. Age demographics were not collected.

Apparatus

This study took place within the same windowless research cubicle used previously. The virtual environment was the same as used previously (see Experiment 4).

Procedure

Upon entering the research cubical, participants were presented with an information sheet that described the aims of the research and outlined participants' ethical rights and a consent form. The experimenter verbally outlined the study to the participant and verbally restated participants' ethical rights. Participants were required to consent to participate before the start of the study. Participants were informed that they would be required to complete a series of orientation trials within the virtual building model but were not informed of the role of the colour band cues or that the cues available for use would vary by trial. The experimenter left the room prior to the start of the acquisition phases.

Similar to previous work, this study had two main trial phases, acquisition phases and orientation test trials. Acquisition phases were identical to those used for Group Experimental within Experiment 4. Once participants had completed both acquisition phases, they were required to complete a series of four orientation test trials. Similar to previous experiments presented, participants were digitally placed into a room within the virtual model and asked to turn to face a non-visible but previously seen target. The cues available within each trial however differed; Trial 1, participants were placed within a room with an external view via a window overlooking the physics building, however, no additional coloured band cues were provided (External landmark cues only). Trial 2, participants were place within a windowless room with no view of the external environment but did have access to accurate colour band cues that matched the layout of cues seen during exploration (Colour band cues only). Trial 3, participants were placed within an external-facing room containing a window overlooking the Student Union building. Colour band cues were also available. Unlike the colour band cues within the second trial however, these cues were inverted so that they were opposite to the pattern learnt during acquisition. Within the model this meant that the north and south walls colour banding were reversed, as were the east and west walls, (Contrast). Trial 4 was similar to Trial 1 in that it placed participants within an external-facing room, overlooking the physics building. Unlike trial 1 however, the colour band cues were available and appeared as they had during the acquisition phase (Control).

All participants completed the same four orientation trials, however the order that these were completed varied by group. This was to ensure that participants' use of the different environmental cues was dependent on the cue availability within the current trial and not as a consequence of trial order. For Group Counterbalance 2, Trial 2 and Trial 3 were reversed. As a consequence these participants completed the contrast trial before the colour band only trial. This was essential within the current study to ensure that cue availability within a previous trial did not impact performance within subsequent trials.

Once participants had completed the orientation test trials, they were debriefed by the experimenter. The experimenter explained the aim of the study and presented participants with a debriefing form. Participants were, if they wished, informed of their performance within the trials before leaving.

Results

All statistical tests were evaluated with respect to an alpha value of .05.

Figure 6.10 present the mean orientation error for both counterbalance groups organised by trial type. From this figure, it is apparent that participants' recorded lowest error within the control trial (external landmark cues and colour band cues available), closely followed by the external only trial. Performance within the colour band cues only trial shows that when participants did not have access to the external landmark cues, their orientation error increased. From this, it appears that the external landmark cues were a key element enabling participants to successfully orient, even when colour band orienting cues were available. The reliance participants placed on the external landmark cues and the poor performance within the colour band cues only trial can be seen as potential evidence that the external landmark cues disrupted learning regarding the colour band orienting cues. Evidence from the contrast trial indicates that this effect was not total, and that the colour band cues did influence participants. Within the contrast trial, participants recorded a higher error rate than both the Control and External only trial, even though external landmark cues were available. Were participants not attending to the colour band cues, no increase in error would be anticipated. Overall, results suggest that the an external view disrupted effective use of the colour band orienting cues, however, this effect was not complete as when the colour band orienting and external landmark cues contrasted, orientation error increased.

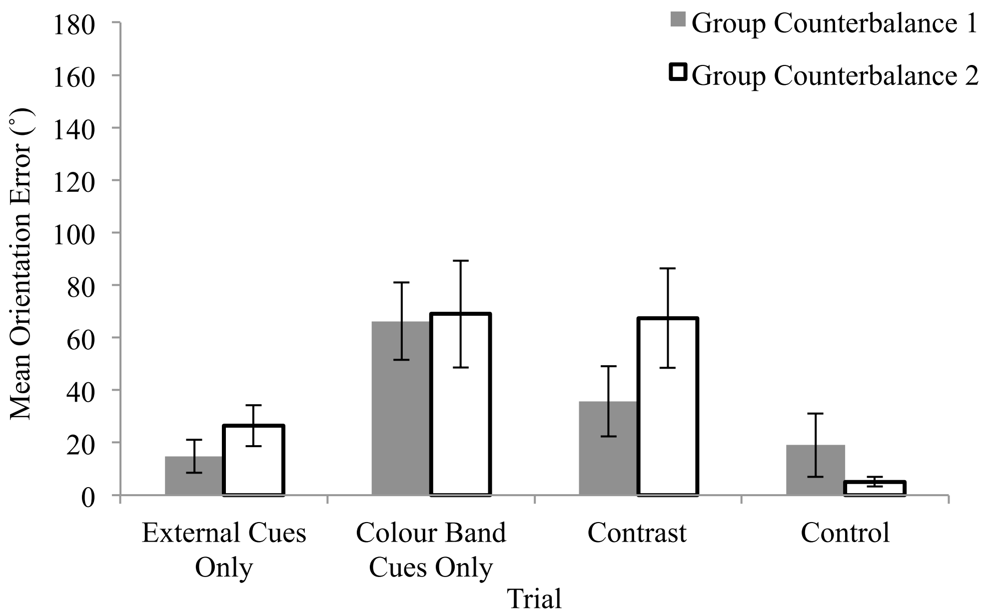


Figure 6.10. Participants orientation accuracy based on cue availability. It can be seen that participants' recorded the lowest error within the control trial when they had access to both the external view and colour band cues. Participants also recorded low error when they had access to external cues. Participants' recorded

highest error when the external view and the colour cues contrasted, suggesting that participants used the colour band cues when making an orientation decision. Error bars represent the estimated standard error of the mean.

A 4 Trial (Control/ External Only/ Colour band Only/ Contrast) X 2 Group (Group Counterbalance 1/ Group Counterbalance 2) mixed design ANOVA was used to analyse the data. Mauchly's test showed that the assumption of sphericity had been violated, $\chi 2(5) = 21.00$, $p<.05$, as such the degrees of freedom were modified using the Greenhouse-Geisser estimates of sphericity, ($\varepsilon = .63$). No significant interactions were observed between Trial and Group, $F(2, 49) = 1.11$, *ns,* $\eta_p^2 = .04$. There was a main effect of Trial, $F(2, 49) = 8.35$, $p<.05$, $\eta_p^2 = .24$, indicating that there was a difference in participants ability to orient across the four trials. To examine where the difference between trials lay, three paired samples *t*-tests, with Bonferronii correction were used, comparing the results from the Control trial, to the other three trials. No significant differences was found between the Control trial ($M= 12.04$, $SD= 32.43$) and the External landmark cues only trial, ($M= 20.63$, $SD= 26.25$), $t(27)=-1.03$, *ns.* The colour band cues did not significantly improve participants' ability to orient when participants had a view of the external environment. It was revealed that there was, however, a significant difference in participants orientation error between the Control trial and the Colour bands only trial, $t(27) = -4.63$, $p<.016$. Participants were significantly more accurate within the Control trial than the Colour bands only trial ($M= 67.58$, $SD= 63.77$). From these results it is clear that participants were significantly more accurate when they had access to a view of the external environment. The high error score recorded within the Colour band only trial suggests that the view of the external environment partially disrupted learning about the colour band cues. Participants were, however, significantly more accurate within the Control trial than the Contrast trial (*M*= 51.61, *SD*= 61.01), $t(27) = -3.13$, $p < .016$. This finding suggests that even though it appears that the available external landmark cues disrupted learning about the colour band cues, the colour band cues did influence participants' orientation decisions. As a consequence, when the colour band cues were placed in opposition to the external view, participants recorded significantly higher orientation error.

Discussion

This study sought to investigate whether the presence of the colour band cues would disrupt the use of external landmark cues within a virtual nested environment. It did this by presenting participants with both external and colour band cues during acquisition. During the orientation test trials, the cue types were presented separately or in contrast to each other. Results suggested that participants primarily used the external landmark cues within the orientation test trials as shown by the external only trial being no different from the control trial and the high error recorded within the colour band only trial. Results from the contrast trial however suggest that many participants relied on the colour band cues as indicated by the increased error within this trial, when these cues contrasted with the external landmark cues. This finding suggests that external cues partially disrupted learning about the colour band cues; however participants had formed an association between the colour band orienting cues and the external landmark targets.

Although not a traditional overshadowing study by design, results in the current study are consistent with previous research which has explored overshadowing within spatial tasks (Chamizo et al., 2003, Redhead & Hamilton, 2007; 2009, Redhead et al., 2013). Results within the current study were not, however, in the direction which would be predicted. Previous studies have demonstrated that the presence of salient visual markers overshadowed learning about the spatial relationships between other available cues. Within the current study, it would be expected that the colour band cues, as salient visual markers, would overshadow learning regarding the external landmark cues. Rather, it appeared that participants learnt about the external environment and the spatial associations which exist between different external cues to a greater extent, learning less regarding the colour band cues and their associations to the external targets. This is clearly demonstrated by participants orientation score within the colour band orienting cues only trial. Performance by Group Experimental in the internal unvisited room in Experiments 4 - 7 demonstrate that the colour band cues could be used to successfully orientate to the target; as such the high error score recorded within the colour band only trial in Experiment 8 was not expected. Furthermore, when using the colour cues to orient as noted earlier it would be anticipated that learning a direct colour external cue association would be easier than learning an external cue to an alternative, non-visible external cue association (Chamizo, et al., 2003). This did not appear to be the case however with participants recording significantly greater error than the control trial.

To suggest that participants' did not attend to the colour band cues within this study would be an oversimplification. Two pieces of compelling evidence can be put forward in support of this claim. Firstly, within the contrast trial, error significantly increased compared to the control trial despite each location having a clear view of the external environment. If the participants solely relied upon the external landmark cues, no differences would be seen between the contrast trial, the control trial and the external only trial. Participants' increase in orientation error within the contrast trial is indicative of participants using the colour band cues to inform their responses. Finally, participant performance within the Coloured band Only trial, although notably worse than the External Only trial, was still significantly better than would be expected by chance (mean value 61.01° compared to a chance value of 90°, $t(27) = -3.33$, $p<.05$). This adds weight to the suggestion that participants were aware of the colour band cues and their role in supporting orientation. From these results, it is clear that the external cues did not completely disrupt learning regarding the colour band cues, but rather demonstrates that participants had a preference for the more traditional external cues.

A key limitation within the present study was that the sample used was undergraduate students who had experience of the real campus and building environment. It is possible that this pre-exposure biased participants to use the cues that they were familiar with using. This could potentially influence participants to choose to use the external cues compared to the colour bands. Thorndyke and Hayes-Roth (1982) demonstrated that participants' ability within orientation tasks is better within familiar rather than unfamiliar environments. This is supported by O'Neill (1992) who investigated participants' ability to navigate and orient within a series of five digital building layouts which varied in complexity. O'Neill found that as familiarity increased, participants' ability to complete wayfinding and orientation tasks increased. Furthermore, despite complexity originally impeding task performance, familiarity overcame this hurdle. This finding was replicated within a questionnaire and a wayfinding task by Prestopnik and Roskos-Edwoldson (2000). Related to the present study, an alternative group of participants with less familiarity with the environment could perform differently within the trials, potentially relying more upon the colour band cues. Expanding this study to investigate a wider sample of individuals with no familiarity with the real campus would have therefore been desirable.

Conclusion

Results from this study demonstrate that the presence of salient external landmark cues within a realistic digital environment disrupt learning about novel colour band cues. It was clear however, from the use of a contrast trial, that this effect was not total. Results from this trial suggested that the colour band cues did appear to influence performance. Overall therefore it is appropriate to suggest that whilst external landmark cues are preferred, colour band cues are not ignored during exploration and orientation test trials within the virtual model.

General Conclusion

Results from Experiment 7 indicated that the associative cues enabled participants to form an association between the colour cues and external landmarks, allowing for accurate orientation decisions compared to the use of internal only and directional cues. Results from Experiment 8, however, showed that participants demonstrated a preference for using external cues. In this respect it appears that participants were more able to form an association between the different external cues and the target, rather than between a colour and target. It would appear that the colour bands acted to support orientation decisions rather than being a key determinant of participants' original orientation choice.

Results within this chapter indicate that the layout of the colour band orienting cues is essential in facilitating participants' ability to orient. Furthermore, it can be seen that the use of these cues can be explained in terms of associative learning principles and established learning theories. These results demonstrate that participants' ability to orient can be facilitated via the use of environmental manipulation; however it remains to be seen whether orientation ability can be facilitated or modified via alternative interventions.

Chapter 7

The impact of Stereotype Threat on Spatial Performance

Research within this thesis thus far has examined the role of environmental manipulations in influencing participants' ability to orient. This chapter examines whether psychological interventions can be used to impact orientation ability, specifically, this chapter explores the role of stereotype threat (Steele & Aronson, 1995) and stereotype lift (Walton & Cohen, 2003) in influencing participants' ability to orient successfully. Can influencing the way participants think about their abilities impact their performance?

Schmader and Johns (2003) define stereotype threat as *"the phenomenon whereby individuals perform more poorly on a task when a relevant stereotype or stigmatized social identity is made salient in the performance situation" (p. 440).* In other words, making individuals aware of negative stereotypes which exist regarding themselves or groups which they associate with can disrupt performance in stereotype related tasks (Steele & Aronson, 1995). Based on this view, those undergoing a stereotype threat experience greater anxiety as they are not only concerned about the task at hand, but also that their performance will confirm a negative stereotype. Stereotype threat has been described as a contributing factor in a variety of persistent social norms including intelligence performance test results of African Americans (Steele & Aronson, 1995; 2004; Sackett, Hardison & Cullen, 2004), the gap between males and females in mathematical ability (Spencer, Steele & Quinn 1999; Ben-Zeev, Fein & Inzlicht, 2005; Huguet & Regner, 2007), even why Caucasian males perform worse on tests of athletic ability (Stone, 2002). One persistent stereotype, which has received less attention regarding the role of stereotype threat, is gender differences within spatial learning (McGlone & Aronson, 2006; Moe, 2009; Rosenthal, Norman, Smith & McGregor, 2012).

Within western society, the stereotype that males are better at spatial tasks than females is well documented (Harris, 1981; Alleyne, 2009). Although research has consistently suggested that the difference between male and females performance within spatial tasks is a consequence of cue usage (Sandstrom, Kaufman & Heuttel, 1998), the influence of societal norms on performance during active spatial tasks is not clear. Can performance within spatial tasks be influenced by increasing or disrupting knowledge of this widely held stereotype?

Although studies directly investigating the link between stereotype threat and performance on spatial tasks are limited, McGlone and Aronson (2006) provide such a study. McGlone and Aronson (2006) presented participants with short questionnaires which made either their gender identity, intellectual ability, or geographical position salient, before asking participants to complete the Vandenberg Mental Rotation Test (VMRT). The VMRT is a standardised test of spatial ability where participants are presented with a target 2D image of a 3D shape, and then required to identify an identical but rotated shape amongst a series of similar distractor shapes. McGlone and Aronson theorised that making gender identity salient would impair female, but improve male performance, due to the societal stereotype, compared to a control condition which made geographical position salient. McGlone and Aronson also theorised that making participants aware of their intellectual abilities should improve performance, compared to the control condition regardless of gender. McGlone and Aronson found that whilst gender differences were consistent with previous research, with males consistently outperforming female participants, a significant interaction between condition and gender was found. When considering female participants, it was apparent that those within the gender awareness condition had the lowest score, suggesting that the stereotype negatively impacted performance. Female participants whose intellectual abilities had been made salient however outperformed females within the other two groups, suggesting a facilitation of performance due to exposure to a positive stereotype, stereotype lift. Results showed that although the gender awareness and intelligence awareness groups did significantly differ, neither significantly differed from the control geographic awareness group. For male participants however, performance within both the gender awareness group and the intelligence awareness condition was higher than that of the control geographic awareness group. Further analysis revealed however that only the gender awareness group differed significantly from the control group. Overall, it is clear from McGlone and Aronson that stereotype manipulation can impact performance in the VMRT. It remained unclear however whether stereotype threat can impact performance on more active orientation and navigation tasks. These findings also suggest that stereotypes can be used to both impede and facilitate task performance.

Stereotype lift (Walton & Cohen, 2003), stereotypes facilitating rather than impeding performance, has been replicated within other mental rotation tasks (Hausmann, Schoofs, Rosenthal & Jordan, 2009). Hausmann et al., found that making males aware of the gender stereotype improved performance; conversely; female performance was not negatively impacted by a corresponding stereotype threat. Rosenthal et al. (2012) expanded the work of McGlone and Aronson (2006) and Hausmann et al. (2009), by combining stereotype threat with an active navigation task. Rosenthal et al. required participants to search for a hidden platform within a digital watermaze after making them aware of a stereotype threat manipulation. Participants were divided by gender and assigned between two navigational task groups (Landmark or Geometry) and between two conditions (Control or Stereotype). The navigational task differed based on the cues available to participants within the watermaze, whilst the stereotype manipulation was a short message, presented prior to the study starting, informing participants that their performance would be compared to other participants of the opposite gender. It was expected that males would outperform females (spend significantly greater time within the correct quadrant of the watermaze) within the geometry condition, but not the landmark condition. In addition, it was hypothesised that making participants aware of the stereotype regarding spatial tasks would improve male and deteriorate female performance. Overall it was found that females were more effective within the landmark condition, spending a greater proportion of their time within the correct region of the pool, compared to the geometry condition. Conversely males spent longer within the correct region within the geometry condition compared to the landmark condition. Although no differences were apparent between males and females based on the landmark task, males did spend significantly longer within the correct quadrant of the water maze in the geometry condition compared to females, supporting the first prediction. In addition, it was found that males' performance was increased, relative to controls, within the stereotype condition, demonstrating evidence for stereotype lift. Females' performance however did not deteriorate as a result of the stereotype threat manipulation, matching the findings of Hausmann et al. (2009). Rosenthal et al. argue that this null result may have been as a consequence of an inadequate control group. Rather than providing a neutral comparison group, it is likely that female participants within the control condition also experienced a stereotype threat, due to the social norm regarding gender differences and spatial tasks. The researchers made no attempt to disrupt existing stereotype knowledge. Further work is necessary therefore to examine if this widely held belief could be disrupted, and if this disruption occurs, whether it is possible to see a difference in female participants' spatial performance.

A key aspect of stereotype threat research examines the conditions necessary for stereotype threat to occur. Rosenthal et al. (2012) demonstrated that the inclusion of a positive stereotype was able to lift performance of male participants, who are anticipated to already be proficient at completing a task. Are only those from minorities and from groups with well-established stereotypes vulnerable to the effects of stereotype manipulation? Aronson et al. (1999) investigated this by exploring stereotype threat related to maths performance using Caucasian male Stanford maths students, who during a pre-test scored above 600 on the maths element of the Scholastic Aptitude Test (a standardised university admission test within the United States, with an average score of 500), and who rated maths as being important to them. As part of the study, all participants were required to complete a 20-minute maths test. Participants within the control condition were informed that the test was just a measure of their mathematical ability. Participants within the experimental condition however were informed of a growing cultural gap regarding mathematical scores between Caucasian and Asian students. Participants within this condition were explicitly told that Asian students frequently outperformed Caucasian students on mathematical tests, and participants were required to skim read a variety of supporting articles. Aronson et al., found that participants within the experimental group solved significantly fewer questions successfully on a subsequent mathematic test. Results indicated that stereotype threat can occur within groups without a previous history of discrimination.

Specifically related to the use of spatial tasks, Moe and Pazzaglia (2006) explored the impact of stereotype manipulation on males and females performance within the VMRT, however unlike McGlone and Aronson (2006) participants were assigned to three conditions (Male superiority, female superiority, control) and were directly informed about spatial stereotypes. Participants were required to complete the VMRT task before being presented with the group manipulation, being told that males or females are better at the VMRT, or that there is no difference. Participants were then required to complete a second version of the VRMT. Moe and Pazzaglia found clear evidence of a stereotype lift and stereotype threat. Regardless of gender, participants who were told of their corresponding gender superiority performance increased, however performance was reduced when told of the opposing gender superiority, whilst no change was induced for control participants. Similarly, in an expansion of Moe and Pazzaglia (2006), Moe (2009) again found that participants' performance on the VRMT was affected by the presence of a stereotype manipulation. Moe (2009) found that when participants were told that females were better than males, no gender differences could be observed. In comparison, when no stereotype manipulation was presented, or participants were told of a male superiority within the task, male participants outperformed female participants. Moe (2009) also explored the influence of perceived task difficulty, and found that males, but not females, were vulnerable to the task difficulty manipulation. These results suggest that both male and female performance within spatial tasks can be influenced by the presence of a stereotype manipulation. The following study seeks to explore whether a similar effect is seen within an orientation task.

Experiment 9 - The influence of Stereotype Threat on Orientation Accuracy within a Virtual Nested Environment Following Active Exploration

There has been mixed results regarding the impact of stereotype threat within spatial tasks. Moe and Pazzaglia (2006) and Moe (2009) demonstrate that female performance can be facilitated within the VMRT when female participants are told that they perform better than their male counterparts. Evidence from Rosenthal et al. (2012) however found that female participants were not influenced by a stereotype treat within an active navigation watermaze task, with no differences being seen between groups.

Female participants experiencing a stereotype threat did not spend significantly less time in the correct quadrant of the pool than female control participants. The present study aims to investigate whether exposing male and female participants to a stereotype threat manipulation impacts their ability to orient within a virtual environment.

The following study seeks to investigate whether a stereotype threat manipulation can impact the performance of participants within the orientation tasks used previously (See Experiment 3). Moe (2009) demonstrated that stereotype threat can be used within spatial tasks to influence performance; this study seeks to replicate this finding within an orientation task.

Based on previous work the following hypothesises can be suggested.

1) Male participants will record lower orientation error than female participants (Coluccia & Louse, 2004).

2) Female participants' orientation error will not be affected by the presence of the stereotype manipulation (Rosenthal et al., 2012)

3) Male participants exposed to a stereotype threat will record greater orientation error than male participants exposed to a stereotype lift (Aronson et al., 1999)

Method

Design

This study used a 2 (Gender) x 2 (Condition) mixed design. Participants were divided by gender (Male and Female) and systematically placed in one of the two conditions, Stereotype Threat or Stereotype Lift.

The dependant variables were participants' orientation error across the four orientation trials. Orientation trials were divided across four rooms and viewpoints, external unvisited, internal unvisited, external visited and internal visited.

Participants

Participants were 40 undergraduate psychology students from the University of Southampton whom completed the study in exchange for credit towards a research participation scheme. 21 participants were male and 19 were female. All participants had prior experience of the campus and Shackleton building; however did not have experience of the virtual model.

Procedure and Materials

This study used the same procedure as used previously (see Experiment 3). To summarise, participants were required to explore a virtual model of the Shackleton building, University of Southampton, before being asked to, within the model, turn to face a series of non-visible, but previously seen targets. The model that participants explored did not contain any colour band orienting cues and as such was the same as used within Experiment 3.

Participants completed two acquisition phases, exploring the external and internal components of the environment whilst following a set route. Prior to starting the acquisition phases participants were presented with the stereotype threat manipulation. Participants within the Stereotype Threat condition were told “Previous research has shown that males/ females (other gender) perform better than males/ females (participant’s gender), probably due to genetic reasons”. Participants within the stereotype lift condition were told that “Previous research has shown that males / females (Participant’s gender) perform better than males/ females (Other gender), probably due to genetic reasons”. Acquisition phases were not timed, and participants were free to explore for as long as they wished. Once participants indicated to the experimenter that they had completed their explorations, they preceded to the orientation trials.

Prior to the start of the orientation test trials, participants were reminded of the stereotype manipulation that they had been told earlier (Stereotype threat, or Stereotype lift). Participants completed four orientation test trials. Participants were placed into either an internal or external-facing room, which they had, or had not, visited during acquisition and were required, to turn to face a non-visible but before seen target. As before, targets were all large elements within the external environment, for example the car park, the student union, physics building and the main campus. Orientation test trials were not timed. Once participants had completed all test trials they were informed of their performance within the task. Prior to leaving the research cubicle, participants were debriefed by the experimenter and presented with a debriefing form to take away with them. The experimenter explained to participants that they may have been deceived due to the implementation of the stereotype threat manipulation, and ensured that participants were aware of the real evidence before leaving.

Results

All statistical analysis presented are compared to an alpha value of .05.

Taken across all trials and groups, male participants recorded lower mean orientation error (Mean = 43.10˚) than female participants (Mean = 52.50˚). Mean orientation error across each trial, for each condition for Male and Female participants is presented in figures 7.1 and 7.2 respectively. From Figure 7.1 it appears that males' performance was influenced by the presence of the stereotype manipulation. This effect is most salient within the internal unvisited room, although a higher error score is apparent for all trials for Group Stereotype Threat. The data for female participants, as shown in Figure 7.2, is not as clear however. Female participants within Group Stereotype Threat recorded marginally lower error scores than females in Group Stereotype Lift. Taken together, these figures suggest that male participants record lower orientation error than females; however, it also appears that males are considerably more vulnerable to a stereotype manipulation.

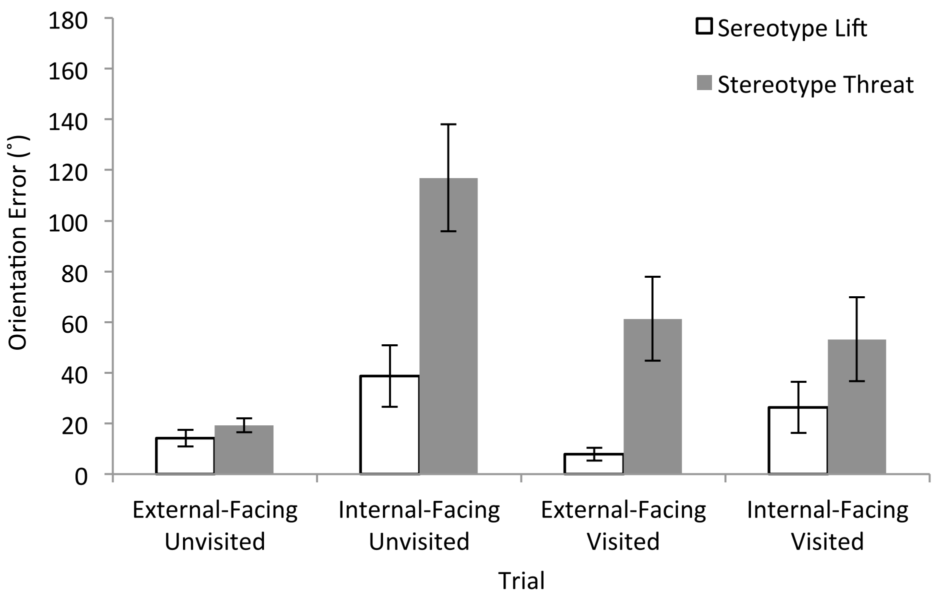


Figure 7.1. Mean orientation error recorded by male participants across the four orientation test trials. It can be seen that male participants within Group Stereotype Threat recorded greater orientation error than participants in Group Stereotype Lift. Error bars represent the estimated standard error of the mean.

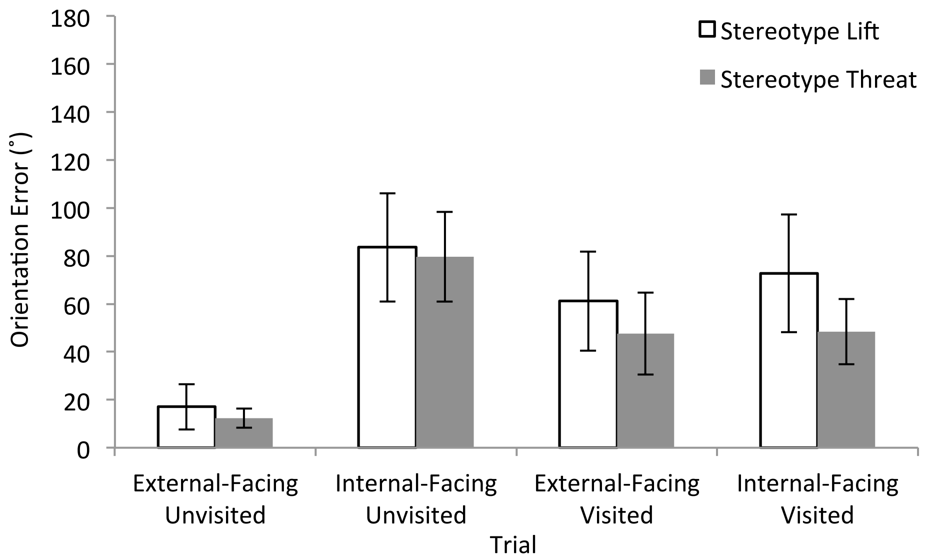


Figure 7.2. Mean orientation error recorded by female participants across the four orientation test trials. No large differences are apparent in orientation error between females in Group Stereotype Lift and Group Stereotype Threat, suggesting the manipulation had limited effect. Female participants within Group Stereotype Lift frequently recorded higher orientation error than those in Group Stereotype Threat. Error bars represent the estimated standard error of the mean.

To examine the differences between conditions in more detail, a 2 Condition (Stereotype Lift/ Stereotype Threat) x 2 Gender (Male/ Female) x 2 Room Type (Internal/ External) x 2 Experience (Visited/ Unvisited) mixed ANOVA was used. The analysis demonstrated that there was no main effect of condition $F(1, 38) = 3.06$, *ns*, $\eta_p^2 = .07$, suggesting that the stereotype manipulation did not directly influence orientation error. In addition no main effect of gender was seen, $F(1, 38) = 1.16$, *ns,* $\eta_p^2 = .04$, suggesting that males and females did not significantly differ in recorded orientation error. A significant interaction was however found between condition and gender, $F(1, 38) = 8.03$, $p < .05$, $\eta_p^2 = .19$. Post hoc analysis via the use of simple main effects revealed that there was a significant effect of gender within the stereotype lift condition $F(1, 38) = 7.65$, $p<.05$, but not within the stereotype threat condition, $F(1, 38) = 1.54$, *ns*. Males recorded lower orientation error than females in the lift condition (Means: Male = 21.75°; Female = 58.62°) but not in the threat condition (Means: Male = 62.67°; Female = 46.99°). Furthermore it was seen that there was a significant effect of condition within the male participants, $F(1, 38) = 10.50$, $p < .05$, but not female participants, $F<1$. Males within Group Stereotype Lift recorded significantly lower orientation error than males within Group Stereotype Threat, demonstrating an effect of the stereotype manipulation. No differences however were observed within female participants.

When examining the effect of experience and room type, no main effect of experience was observed, $F<1$, *ns*, $\eta_p^2 = .001$, visiting a room previously did not influence participants orientation accuracy. There was, however, a main effect of room type, $F(1, 38) = 21.44$, $p < .05$, $\eta_p^2 = .38$. Participants were more accurate when orienting in rooms with a view of the external environment rather than rooms that overlooked the inner courtyard. A significant interaction was observed between experience and room type, $F(1, 38) = 18.37$, $p < .05$, $\eta_p^2 = .34$. Simple main effects analysis revealed that there was a significant effect of room type within the unvisited rooms, $F(1, 76) = 39.80$, $p < .05$, but not for visited rooms, $F<1$, *ns*. This suggests that participants were able to orient within the internal-facing rooms if they had visited the location previously, however, were not able to orient when they had neither visited a location previously or have access to a view of external environment.

A significant interaction was also seen between condition, experience and room type, $F(1, 38) = 5.14$, $p < .05$, $\eta_p^2 = .11$. Simple main effect analysis revealed that there was a significant effect of condition within the unvisited internal-facing room, $F(1, 152) = 7.35$, $p < .05$. Participants within the stereotype lift condition recorded lower orientation error within the internal unvisited room than participants undergoing a stereotype threat. No significant effects of condition were seen within the other rooms however, (visited external $F(1, 152) = 1.75$, *ns*, unvisited external, visited internal *F*s<1, *ns*).

Overall results suggest that exposure to a stereotype influenced males ability to successfully orient within a virtual building model, with males in Group Stereotype Lift recording lower orientation error than males within Group Stereotype Threat. No differences were seen however for female participants as a consequence of stereotype exposure. In addition, consistent with previous findings, it was seen that experience and room type influenced participants' orientation error.

Discussion

Results are consistent with earlier research within this thesis that has identified an impact of room type and experience on participants' ability to orient within digital nested environments. Results also demonstrate an effect of stereotype manipulation within male participants. Males exposed to a stereotype lift manipulation recorded lower orientation error than those exposed to a stereotype threat. No difference was seen however in the errors recorded by female participants based on stereotype manipulation. The finding that female orientation accuracy was not influenced by the stereotype manipulation is consistent with previous research investigating stereotype threat within active spatial tasks (Rosenthal et al., 2012).

Previous research investigating stereotype manipulation within spatial tasks, (Rosenthal et al., 2012) reports similar findings. Rosenthal et al. (2012) found that making males aware of a positive stereotype improved performance within a virtual watermaze task, but did not influence females. Within the current task, male performance was impacted by the presence of the stereotype manipulation while female performance was not. Two key arguments can be suggested for why females were not affected by the manipulation. Firstly, it may be that as females are frequently exposed to a negative social stereotype regarding their spatial abilities, the manipulation used within this study was insufficient to impact behaviour. Females being told they are expected to perform worse acknowledge a well-known stereotype, whereas females told they are expected to perform better simply do not believe the experimenter. If this were the case, we would not expect to see improved orientation for females within Group Stereotype Lift. Secondly, females may be experiencing a floor effect within this study. Previous evidence within this thesis suggests that without the colour band orienting cues, participants record high orientation error particularly in the Internal Unvisited room where the effect of condition was significant across genders. Female participants' performance in the threat condition does not deteriorate compared to the lift condition as may be already no better than chance. As female participants are unable to accurately complete the task in either condition, performance is not modified. This explanation can be explored if the colour band orienting cues are included within the model. If these cues are available, it would be anticipated that both male and female participants will be able to complete the orientation task. Consequently, it may be possible to see if the stereotype manipulation impacts female participants' performance.

Although differences between the male stereotype manipulation groups are apparent within all trials, this is most apparent within the internal unvisited room. One possible explanation is that Group Stereotype Lift developed a more complete understanding of the internal lay out of the building. For example, within the internal unvisited room it is possible to see the large computer room, a room with an external view and a location visited previously during the acquisition phases. If participants are aware of this room and its location relative to the external cues, they would be able to orient effectively. It is possible that males in Group Stereotype Lift were more able to use the cues available within the internal unvisited room, for example the view of the large computing room, than males in Group Stereotype Threat. Participants unaware of this relationship would however be unable to accurately complete this trial. The mean error recorded by males in Group Stereotype Threat within the unvisited room is considerably higher than recorded by Group Control in Experiments 3 and 4; as such it would appear that this downgraded performance is a consequence of the stereotype threat. Due to the lack of a control group within the current study it is not currently possible to know if this difference is a consequence of stereotype threat, lift, or a combination of both effects.

This finding is consistent with Rosenthal et al., who found that males' performance in a virtual watermaze improved within trials that did not contain landmark cues when informed of a positive stereotype. The presence of the positive stereotype acted to facilitate male participants' ability to use non-landmark cues, including the environments geometric features. Females, in contrast, have been shown to be reliant on landmark rather than geometric cues (Galea & Kimura, 1993), and as such were unable to complete the task accurately regardless of the presence of the stereotype lift. As a consequence it is necessary to repeat the current study within an environment where female participants are able to accurately orient. This can be achieved by including the colour band orienting cues within the environment.

Conclusion

Overall, results from this study indicate that males, but not females were influenced by a spatial stereotype manipulation. After being told that they were expected to perform well compared to females, male participants recorded reduced orientation error compared to males who had been told that that they were expected to perform poorly. Female participants, however, were not affected by the stereotype manipulation. The nature of the task however may partially explain this result. As such it would be beneficial to repeat this task when participants have access to the colour band orienting cues presented previously.

Experiment 10 – Stereotype Threat Impacts on Orientation Accuracy within a Virtual Nested Environment

Results from Experiment 9 indicated that female participants were not affected by the presence of a stereotype threat manipulation. These finding consistent with Hausmann et al. (2009) who demonstrated a similar finding within a mental rotation task and Rosenthal et al. (2012) who identified a similar finding within an active watermaze navigation task. It was argued, however, that this may partially be a consequence of female participants experiencing a floor effect within the orientation test trials. In their studies of stereotype threat, Quinn and Spencer (2001), and Steele (1997), discuss the importance of pitching the task at the right level; it needs to be difficult enough so people feel they have reached their limit of ability, but not so difficult that the task is deemed impossible and the stereotypes become irrelevant. Previous research has demonstrated that, without the colour band orienting cues, female participants' record higher error than male participants within the orientation test trials. To illustrate this point, if we return to the results gathered within Experiment 4, a significant 4 way interaction can be seen between room type, experience, condition and gender, $F(1, 36) = 6.91$, $p<0.05$. Further analysis via simple main effects revealed that there was an effect of gender in Group Control in the unvisited internal-facing room, $F(1, 144) = 8.96$, $p<0.01$. No effect of gender was however seen within Group Experimental. Without the colour band cues females recorded higher orientation error than males, but this gender gap was removed by the addition of the colour band cues. By providing participants with the colour band orienting cues, an examination of stereotype threat within a spatial task that both genders are capable of completing will be possible.

The following study seeks to explore whether stereotype manipulations can be used to boost (Stereotype lift), or impede (Stereotype threat) participants' accuracy when they are required to orient within the virtual building model presented previously. In addition, to address a weakness of Experiment 9, a control group was added to determine whether a lift or threat is responsible for any recorded differences between stereotype manipulation groups. To clarify, participants will be assigned to either a control group, whereby participants are told that there was no difference in task performance between males and females, or one of two stereotype manipulation conditions, a stereotype threat condition, whereby participants are told that they are expected to perform worse than the other gender and a stereotype lift condition, whereby participants are be told they are expected to perform better than the other gender. Participants will be required to complete the same orientation trials used previously; however the colour band orienting cues, as used within Experiment 4, will be present to assist participants.

This study uses the passive methodology used within Chapter 5. Results using this methodology were highly similar to those uncovered when compared to an active paradigm, suggesting passive interactions are a viable and appropriate tool for this investigation.

From current literature the following hypotheses can be proposed:-

1. Participants exposed to a Stereotype Threat manipulation will record greater orientation error than control participants and participants exposed to a Stereotype Lift manipulation (McGlone & Aronson, 2006; Aronson et al., 2006).
2. Participant exposed to a Stereotype Lift manipulation will record lower orientation error than participants presented with no stereotype manipulation (Hausmann et al., 2009; Rosenthal et al., 2012).

Method

Design

This study used a 4-way mixed factorial design. The independent variables were room type (External/ Internal), experience (Visited/ Unvisited) [within], gender (Male/ Female) and condition (Stereotype Lift/ Stereotype Threat/ Control) [between]. The dependant variable was orientation error.

Participants

Participants were 50 University of Southampton undergraduate students. 13 participants were male and 37 were female. Group Control consisted of 4 male and 13 female participants, Group Stereotype Threat consisted of 5 male and 16 female participants and Group Stereotype Lift consisted of 4 male and 8 female participants. Participants completed this study as part of a research demonstration during a behavioural neuroscience tutorial. Participants received no compensation for time spent completing this research study. All participants had experience of the real University campus but had not seen or interacted with the model previously. All participants had normal to corrected normal vision.

Apparatus

For this study participants watched the same video tours which were presented to Group Experimental in Experiments 5 and 6. For details on these video tours, please see Experiment 3. The study took place within the same lecture theatre as used previously.

Procedure

Participants completed this study as part of a group tutorial activity. The experimenter explained to participants that the aim of the research was to explore the extent to which individuals were able to track their position within internal spaces. Participants signed a formal consent form prior to completing this study, and were informed by the experimenter that their participation was voluntary.

Prior to the start of the main study, participants were asked to indicate their gender on a “clicker” response system which recorded each participant’s answers, and provided an opportunity to both ensure participants were familiar with the clicker system, and as a method to allow the experimenter to collect demographic data. Once participant demographic data had been collected, the experimenter presented the stereotype manipulation to the group in the form of a verbal message. Participants were told either that "*Today you will be taking part in a spatial task. There has been much research into this area, some of which has looked specifically at gender differences. It has been found that men and women use different strategies when navigating, although no significant differences have been found in their spatial performance (Sandstrom, Kaufman, & Huettel, 1998)."* (Group Control), *"Today you will be taking part in a spatial task. There has been much research into this area, some of which has looked specifically at gender differences. It has been found that men and women use different strategies when navigating, although men are often found to outperform women on spatial tasks (Dabbs, Chang, Strong, & Milun, 1998)."* (Male Stereotype Lift/ Female Stereotype Threat) or *"Today you will be taking part in a spatial task. There has been much research into this area, some of which has looked specifically at gender differences. It has been found that men and women use different strategies when navigating, and on certain tasks females outperform males in their spatial performance (Duff, & Hampson, 2001)."* (Male Stereotype Treat/ Female Stereotype Lift). This information was also presented on a PowerPoint slide prior to the start of the study, including a full citation for the referenced journal article.

Other than the addition of the stereotype manipulation, the procedure used was the same as Experiment 5.

Once all four orientation test trials had been completed, participants were verbally debriefed by the experimenter. The experimenter explained that participants may have been deceived due to the stereotype manipulation, and ensured participants were aware of the real evidence. Prior to leaving, participants were presented with a debriefing form.

Results

Data Analysis

The data analysis used within this study the same as that used for Experiment 5.

All statistical analysis presented are compared to an alpha value of .05.

When examining the impact of stereotype manipulation, it was apparent that the data followed the anticipated trend. Across all trials and groups, it was seen that male participants recorded lower mean orientation error (Mean = 22.88˚) than female participants (Mean = 32.67˚). Participants exposed to a stereotype threat manipulation recorded highest mean orientation error (Group Mean = 46.97˚, Male Mean = 40.50°, Female Mean = 53.44°), whereas participants exposed to a stereotype lift manipulation recorded lowest mean error (Group Mean = 11.25˚, Male Mean = 5.63°, Female Mean = 16.88°). Participants who were not presented with a stereotype manipulation performed as expected between these groups (Mean = 25.10˚, Male Mean = 22.50°, Female = 27.69°). Mean orientation error across each trial, for each condition for male and female participants is presented in figures 7.3 and 7.4 respectively.

From Figure 7.3 it appears that males assigned to Group Stereotype Threat recorded higher orientation error than males within Group Stereotype Lift and Group Control. It was seen that with the exception of the external unvisited room, males within Group Stereotype threat recorded higher error than the other groups. The data for female participants, as shown in Figure 7.4, demonstrates a far clearer effect of the manipulation. Female participants within Group Stereotype Threat recorded considerably higher error than females in Group Stereotype Lift and, within the internal-facing rooms, considerably greater error than females within Group Control. Taken together these figures suggest that male participants record lower orientation error than females and, counter to what was seen within Experiment 9, females are also susceptible to a stereotype manipulation.

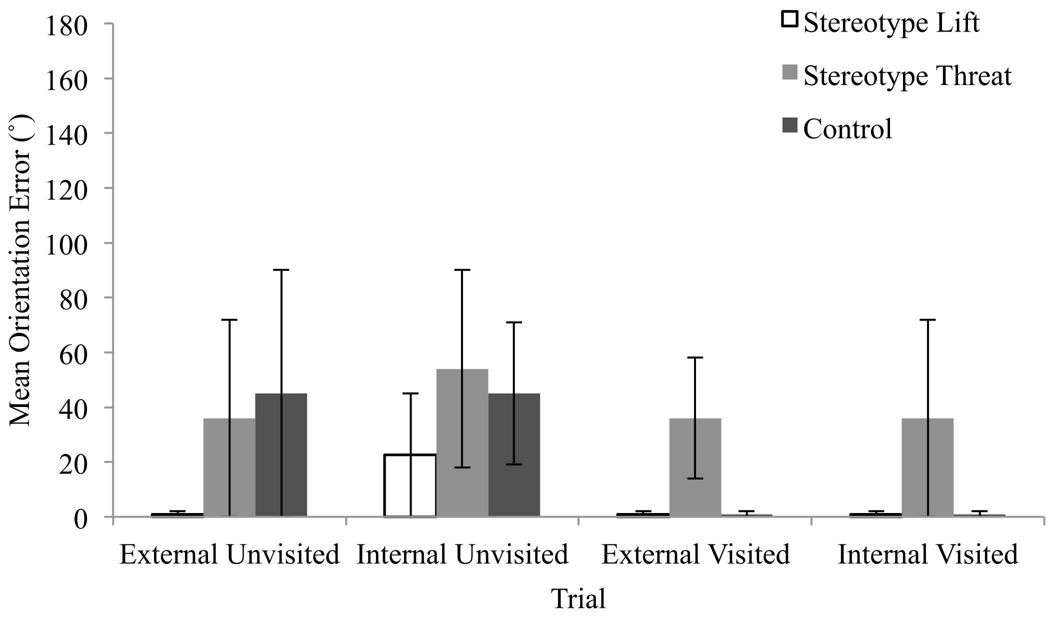


Figure 7.3. Mean orientation error recorded by male participants across the four orientation trials within Experiment 10. It is seen that Group Stereotype Threat consistently recorded greater error than Group Stereotype Lift or Group Control. Note that the absence of histogram and error bars denotes that no participants recorded errors within those conditions. Error bars represent the estimated standard error of the mean.

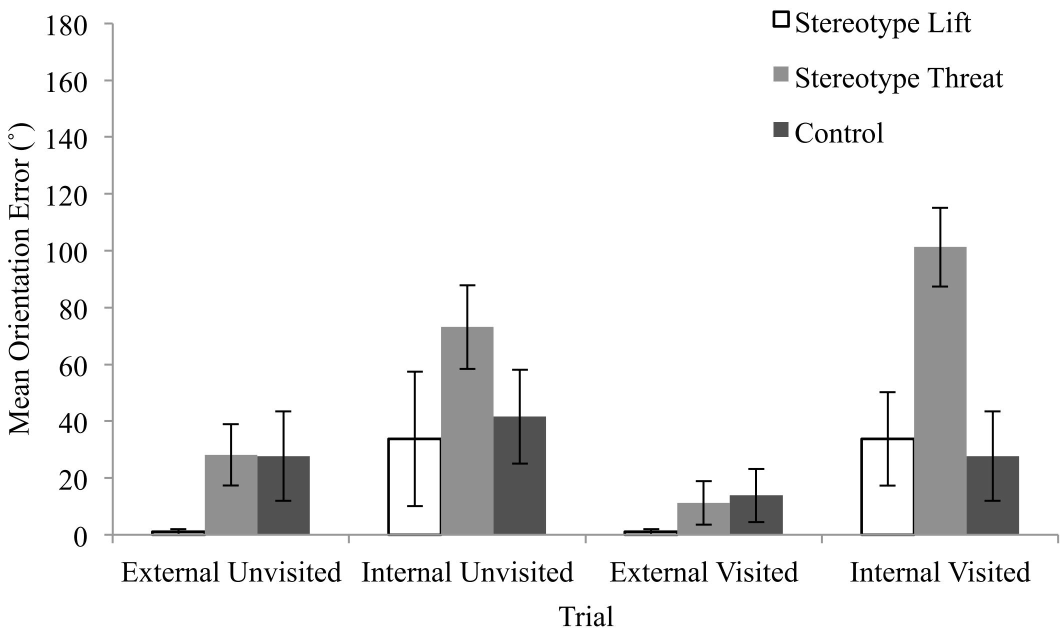


Figure 7.4. Mean orientation error recorded by female participants across the four orientation trials within Experiment 10. Data suggests that the female participants were vulnerable to the stereotype manipulation, with females in Group Stereotype Threat recording considerably higher mean orientation error than Group Stereotype Lift or Group Control. This effect is most apparent within the internal-facing rooms. Note that the absence of histogram and error bars denotes that no participants recorded errors within those conditions. Error bars represent the estimated standard error of the mean.

To examine the differences between conditions in more detail, a 3 Condition (Control/ Stereotype Lift/ Stereotype Threat) x 2 Gender (Male/ Female) x 2 Room Type (Internal/ External) x 2 Experience (Visited/ Unvisited) mixed ANOVA was used. The analysis demonstrated a main effect of condition $F(2, 44) = 4.32$, $p<.05$, $\eta_p^2 = .17$. This suggests that the stereotype manipulation did influence participants' orientation error. Subsequent Newman-Keuls analysis revealed that there was a significant difference between Group Stereotype Threat and Group Stereotype Lift, $q = 4.5$, there was also a significant difference between Group Stereotype Threat and Group Control, $q = 3.1$. No significant difference was observed however between Group Stereotype Lift and Group Control.

No main effect of experience was observed, $F(2, 44) = 2.43$, *ns,* $\eta_p^2 = .05$. Previous experience of a room did not influence participants' orientation accuracy. There was however a main effect of room type, $F(1, 44) = 12.20$, $p< .05$, $\eta_p^2 = .22$. Participants' recorded lower orientation error within the external-facing rooms. No main effect of gender was seen, $F<1$, *ns*, $\eta_p^2 = .02$, suggesting that males and females did not significantly differ in recorded orientation error.

No significant interaction was observed between condition and gender, $F<1$, *ns,* $\eta_p^2 = 003$. A significant interaction was, however, found between room type and gender, $F(1, 38) = 5.99$, $p< .05$, $\eta_p^2 = .12$. Post hoc analysis via the use of simple main effects revealed that there was a significant effect of room type for female participants $F(1, 44) = 17.65$, $p< .05$, but not for male participants $F<1$, *ns*. Furthermore, it was found that there was a significant effect of gender within the internal-facing rooms, $F(1, 88) = 4.63$, $p< .05$, but not within the external-facing rooms, $F<1$, *ns*. This suggests that males and females orientation accuracy did not differ within the external-facing rooms, but females recorded higher error within the internal-facing rooms. This effect was independent of the stereotype manipulation as no interaction between room type and condition, $F(2, 44) = 1.96$, *ns*, $\eta_p^2 = .09$, was found and no interaction was found between condition, gender and room type, $F(2, 44) = 1.12$, *ns,* $\eta_p^2 = .05$. No other main effects or interactions were significant.

Results from this study demonstrate that participants' ability to orient was impacted by the presence of a stereotype manipulation, participants exposed to a stereotype threat recorded significantly higher orientation error than participants exposed to either no stereotype manipulation or a stereotype lift.

Discussion

Results demonstrate that participants' ability to orient can be influenced by the presence of a stereotype manipulation. Data suggests that those exposed to a stereotype lift recorded the lowest mean orientation error, whilst participants exposed to a stereotype threat manipulation recorded highest mean orientation error.

Findings match those reported by McGlone and Aronson (2006) and Moe (2009) who found that the addition of a stereotype manipulation negatively impacted performance of female participants when asked to complete the VMRT. Results also support the view that a positive stereotype facilitated performance. McGlone and Aronson (2006) also found that participants' performance would be facilitated by the presence of a positive stereotype, a finding matched within the current study. This suggests that stereotype manipulations can consistently influence performance within spatial tasks.

One point that should be raised is that in many regards, it can be thought that when participants are using the colour band cues to orient, they are not actually completing a spatial task. Results from Experiment 7 demonstrated that rather than learning about the spatial arrangement of the cues, participants were learning simple associations between the colour band cues and external landmark targets, for example learning that the green band is associated with the car park. This suggests that the stereotype threat acted to disrupt participants' ability to learn these associations. This may be as a consequence of the induced anxiety of the stereotype threat (Steele & Aronson, 1995). Hund and Minarik (2006) found that when asked to navigate through a model town, participants with higher spatial anxiety recorded greater error than those low in spatial anxiety. Furthermore it was found that as the number of landmark cues decreased, navigational error increased. Both of these findings are compatible with the current results. If the induction of a stereotype threat is associated with greater anxiety (Steele & Aronson, 1995), then those experiencing greater anxiety recorded higher error. In addition, the internal-facing rooms, wherein participants recorded greatest error did not have access to landmark cues. Schmitz (1999) found that when exploring an unfamiliar virtual building as self-reported spatial anxiety increased, so did reliance on landmark cues. It may be that within the current study, threatened participants experienced greater anxiety and became focused on the landmark cues within the environment as opposed to learning the associations between the colour band cues and the external landmark cues. As the induced anxiety disrupted participants ability to use non landmark targets, female participants became unable to complete the task, as demonstrated by the high recorded orientation error within the internal-facing rooms for females in Group Stereotype Threat.

Interestingly, within an active virtual watermaze task Rosenthal et al. (2012) did not find evidence that a stereotype threat manipulation influenced female participants, counter to both the findings of the current study, McGlone and Aronson (2006) and Moe (2009). One factor that may partially explain this effect is the role of interactivity. McGlone and Aronson (2006), Moe (2009) and the current study were reliant on passive tasks. This can be compared to Rosenthal et al's. study which was reliant on participants interacting and exploring a virtual watermaze. Indeed, when compared to the active exploration task of Experiment 9, this finding matched. It may be that the active component of the acquisition phases and direct control over orientation decisions acts to "buffer" females from the impact of the stereotype manipulation. This possibility should be explored further within alternative active spatial tasks. Further work is needed to explore the effect of stereotype manipulations on different spatial tasks, for example the active navigation task of exploring a virtual maze.

The significant effect of the stereotype manipulation is especially salient when considering that all participants had experience of the real Shackleton building. Previous research (Thorndyke & Hayes-Roth, 1982; Prestopnik & Roskos-Ewoldsen, 2000) has identified that familiarity with an environment improves the ability to both orient and navigate. Participants within this study would be expected to be familiar with the overall environment used within this study. It would be anticipated that familiarity would act to buffer participants from the anxiety of the stereotype threat. One potential approach to explore this issue is the use an environment that participants are not familiar with, for example a fictitious building environment or a virtual maze. In an unfamiliar environment participants may be more vulnerable to the stereotype manipulation.

A key limitation of this study was that it only examined orientation decisions. Within everyday life there is no doubt that the ability to accurately orient and to identify the direction of a target is important, and often seen as a precursor to any navigation activity (Parush & Berman, 2004) however it is also clear that this is not a decision that participants make only once. To address the impact of stereotype manipulations upon spatial ability the next study will examine participants' performance within a novel virtual maze. Investigating participants' performance within a more active navigation task will help develop a clearer image of the extent to which the stereotype threat manipulation is impacting performance. The use of a virtual maze is advantageous as participants will not be familiar with the environment, providing an opportunity to remove this potential bias.

Conclusion

This study has identified that orientation accuracy can be influenced by stereotype manipulations. Participants exposed to a stereotype threat recorded higher orientation error than control participants or participants exposed to stereotype lift. It has been argued that the stereotype threat reduced orientation accuracy as it induced anxiety within participants (Steele & Aronson, 1995), who in turn became more reliant on traditional landmark cues within the environment (Hund & Minarik, 2006; Schmitz, 1999). Participants subsequently record higher error when landmark cues were not available, primarily within the internal-facing rooms, as threatened participants failed to learn about the associations between the colour band cues and the external landmark targets. Results indicate that the difference between stereotype groups is due to threat manipulation impeding performance as Group Stereotype Threat are different from Group Control while Group Stereotype Lift is not. This may be due to ceiling effect in this study however as the task was made easier with the addition of the colour band orienting cues. This is particularly apparent in the males; Group Control mean error was already low in the external and internal visited rooms so could not be reduced further. Consequently, it would be beneficial to repeat Experiment 9 with a control group to see if stereotype lift is playing significant role in the orientation error recorded by males within the stereotype manipulation groups.

Experiment 11 – Stereotype Threat within an active Virtual Navigation Task

Results from Experiment 9 indicated that male, but not female, participants were vulnerable to a spatial stereotype manipulation. Male participants informed that they were expected to perform poorly within a series of orientation trials recorded higher orientation error than male participants who were told that they were expected to perform well. Results from Experiment 10, however, suggest that when females are presented with a spatial task they can do, they are also vulnerable to experiencing a stereotype threat. Both Experiment 9 and 10 however utilised on an environment with which participants already had a degree of familiarity. Experiment 11 sought to address this by presenting participants with a stereotype manipulation within an active navigation spatial task using an unfamiliar environment, a virtual maze. Participants were required to learn an inefficient route around a virtual maze before being required to find the fastest route to the end. If results are consistent with Experiment 9, it would be anticipated that male participants would be affected by the presence of stereotype manipulation and female participants would not be. If results are consistent with Experiment 10, both genders should demonstrate evidence of stereotype manipulation. By making participants explicitly aware of (potentially fictional) gender differences, it is hoped that results from Experiment 9, Experiment 10 and Rosenthal et al.'s study can be expanded.

Within this study, both male and female participants will be presented with a stereotype manipulation. Participants will then be guided around a virtual maze, by following a predetermined inefficient route for two trials. Participants will then be asked to retrace the route that they have been following. Finally participants' knowledge of the maze will be examined by requiring them to reach the end of the maze in the fastest time possible. It would be anticipated that participants experiencing a stereotype threat will record greater latencies and travel greater distance within the trials than participants undergoing a stereotype lift as performance becomes impeded.

The following hypothesis can be generated based on previous research and the findings of Experiment -

1. The presence of a stereotype threat manipulation will disrupt participants' performance within the virtual maze trials.

Method

Design

This study used a mixed design. The independent variables were gender (Male/ Female) and Condition (Stereotype Threat/ Stereotype Lift). The dependent variables were latency escaping the maze across the different trials and the distance travelled within each trial.

Participants

Eleven male and 33 female A-level students, aged 16 – 17 years, visiting the University of Southampton participated within this study as part of a research outreach activity. Group Stereotype Threat had 6 male and 15 female participants; Group Stereotype Lift had 5 male and 18 female participants. Although a control group was conducted as part of this research, consisting of 14 female participants, this group was dropped from the analysis due to a lack of male participants. Participants were not offered compensation for their time spent completing this research study.

Apparatus and Materials

This study took place within a computer lecture room within the academic unit of psychology, University of Southampton. The lecture room contained 68 identical computers. The virtual maze was displayed upon the computers using identical 19-inch LCD monitors.

This study used a virtual maze. This maze was developed by Dr Matt Jones, University of Southampton, using 3DSMax 2012. The programme placed the participants within the environment and offered a first person perspective. Participants controlled their movement using the “FORWARD” “LEFT” and “RIGHT” arrow keys, but could not look up or down, or interact with items within the environment. Participants were instructed not to use the “BACK” arrow key in order to better simulate real life movement. The maze placed participants at head height approximately 5 feet above the ground. The walls were approximately 6 feet high so that participants could not see above them into the corridors beyond. There was however no celling within the maze as such participants were able to see cues placed outside of the environment. An overhead plan of this maze is presented in Figure 7.5.

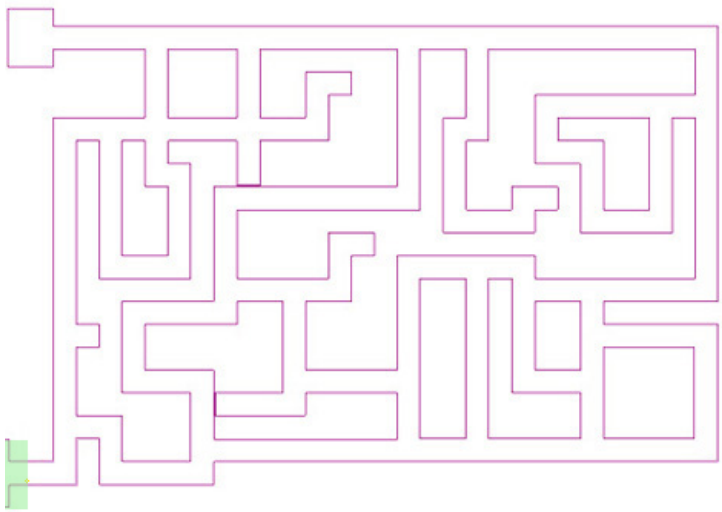


Figure 7.5. Overhead plan of the maze participants explored during this study. The green rectangle at the bottom left of the maze represents the end location. Participants started in the box directly above this location.

The maze contained three types of cue, instruction cues, local cues and distal cues. Instruction cues provided participants with direct instructions regarding the route they should take within the maze, for example “Turn Right at the next junction” (see Figure 7.6). These cues were used within the initial two trials to guide participants around the maze. The route participants were guided around was however far from optimal (see Figure 7.7 for an image of this route). This was to examine whether in later trials participants would continue with the route they had learnt or attempted to find a more efficient path. The instruction cues were not present within the maze during Trial 3 and Trial 4. Local cues took the form of small posters placed throughout the maze. Local cues could be used as landmark cues that participants could use to learn a route within the maze, for example participants could learn to turn left at the image of an apple computer. Example local cues are shown in figures 7.8 - 7.9. Finally, four distinct distal cues surrounded the axis of the maze, based on cardinal direction, i.e. a northern distal cue, an eastern distal cue, a southern distal cue and a western distal cue. These cues could be seen from most points in the maze. By using the distal cues, participants could calculate their approximate position within the maze and navigate to the exit. Example distal cues are presented in figures 7.10 – 7.11.

Figure 7.6. Example instruction cue within the virtual maze. Instruction cues were present for the first two trials to ensure participants learnt a route through the environment.

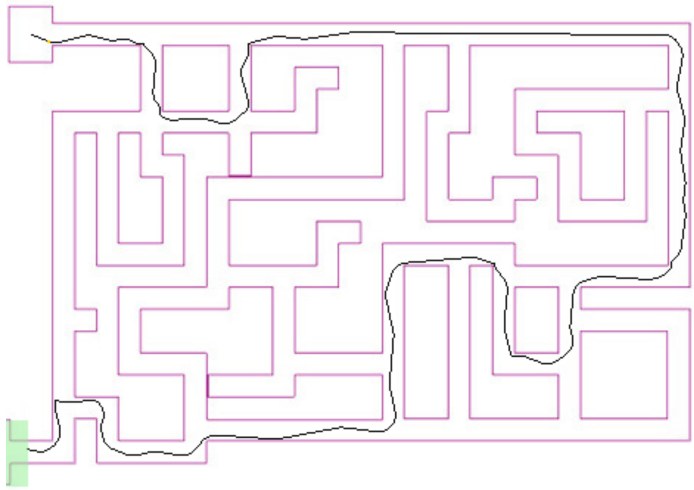


Figure 7.7. The inefficient route taught to participants during Trial 1 and Trial 2. Participants were taught to travel around the perimeter of the maze rather than using the available short cut.

Figure 7.8. Example local cue used within the virtual maze. All local cues took the form of posters placed at junctions.

Figure 7.9. Example local cues used within the virtual maze. Two local cues are visible in this figure, the art print and the pig. A larger distal cue, the clock, is present in the background.

Figure 7.10. Example distal cue. There were four distal cues within the maze, one on each cardinal direction. These were placed outside of the maze itself allowing them to be seen throughout the maze.

Figure 7.11. Example distal cue. It can be seen that despite the maze wall partially obscuring the view the distal cue, the book pile, can be clearly seen. A local cue, the poster of the bus, is also visible.

Procedure

Participants completed this study as part of a group visit day to the University of Southampton. The experimenter introduced themselves and gave the participants a basic introduction to spatial psychology. During this introduction, participants were told that either males, or females, perform significantly better in the type of activity they would be asked to complete, the stereotype manipulation. The experimenter explained the maze task to participants, and verbally outlined participants' ethical right, a script of which is available within Appendix 7.1. Participants were required to sign a consent form prior to starting the maze activity. Participants were again informed of the stereotype manipulation to ensure that this was salient before starting the activity. The stereotype manipulation was also visible at the front of the room throughout the study (See Figure 7.12)

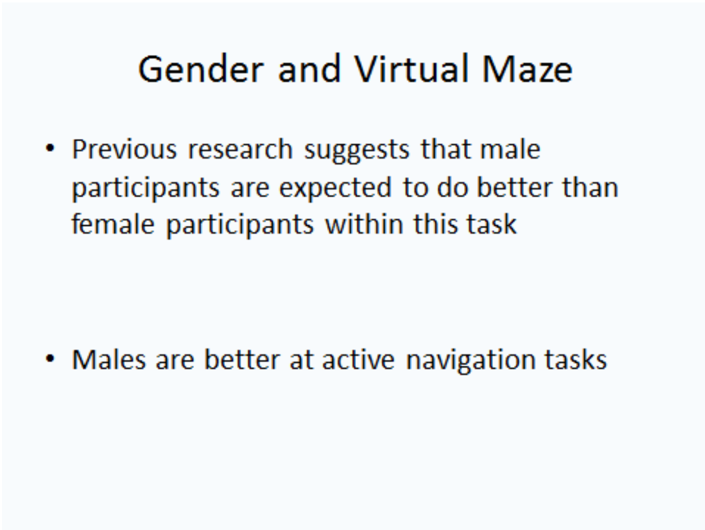


Figure 7.12. Stereotype manipulation message shown to one group of participants prior to and during the study. This message acted as the stereotype lift for male participants and the stereotype threat for female participants and was clearly displayed at the front of the lecture theatre.

For the maze task, participants completed four trials. The first two trials taught participants a route within the maze to the exit. During these two trials, all three cue types (instruction, local and distal) were available for participants to use (Trial 1 and Trial 2). For the third trial, participants were required to retrace the same route, however the instruction cues were removed (Trial 3). For the final trial, participants were instructed to find the fastest route to the end of the maze. Again no instruction cues were present for this trial (Trial 4). The shortest route is illustrated in Figure 7.13.

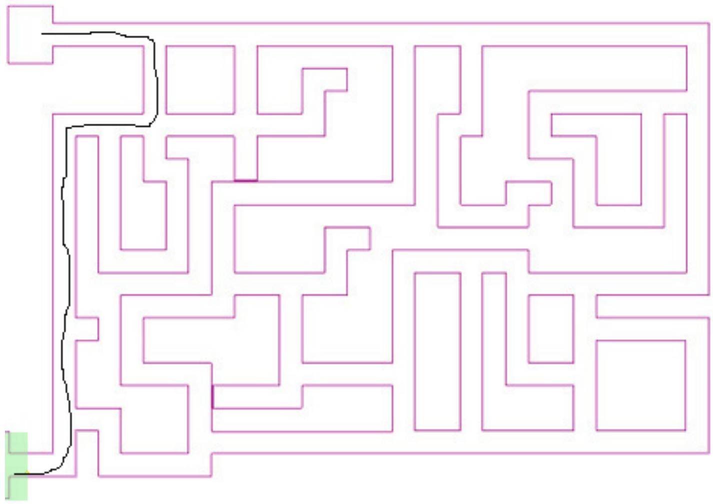


Figure 7.13. The shortest route within the maze and the ideal route for Trial 4.

Each trial was capped at a maximum of 3 minutes, at which point the trial would automatically end and the study would proceed to the next trial. A summary of the four trials is presented within Table 7.1.

Table 7.1. Trial and cue availability summary.

Trial	Cue Availability			Trial Description
	Instruction Cues	Local Cues	Distal Cues	
Trial 1	✓	✓	✓	Participants instructed to follow instructions around maze to learn a route
Trial 2	✓	✓	✓	Participants instructed to follow instructions around maze to learn a route
Trial 3	×	✓	✓	Participants instructed to follow previously learnt route around the maze to assess learning
Trial 4	×	✓	✓	Participants instructed to find their way to the end of the maze in the shortest time possible, using any route they wish.

Once all participants had completed the maze activity, the group was verbally debriefed by the experimenter, who explained the study, and informed participants of the stereotype manipulation and deception employed. A transcript of the initial debriefing is provided within appendix 7.2. Prior to leaving the study room, participants were provided with a written debriefing statement.

Results

Data Analysis

The virtual maze programme tracked participants' movements at all times. Participants' latency and distance travelled within the maze was therefore provided by the programme output. The programme also provided images of the route participants had taken during each of the trials.

All statistical tests are reported to an alpha value of .05.

Figure 7.14 and Figure 7.15 presents participants' latency across the four trials, for males and females respectively. It can be seen from these figures that male participants appeared to be affected more by the presence of a stereotype threat manipulation than female participants whose performance remained relatively constant between threat conditions and, in contrast to male participants', Group Stereotype Threat actually record shorter latencies than Group Stereotype Lift. Males in Group Stereotype Lift had shorter latencies in the trials than males in Group Stereotype Threat, and females in either condition.

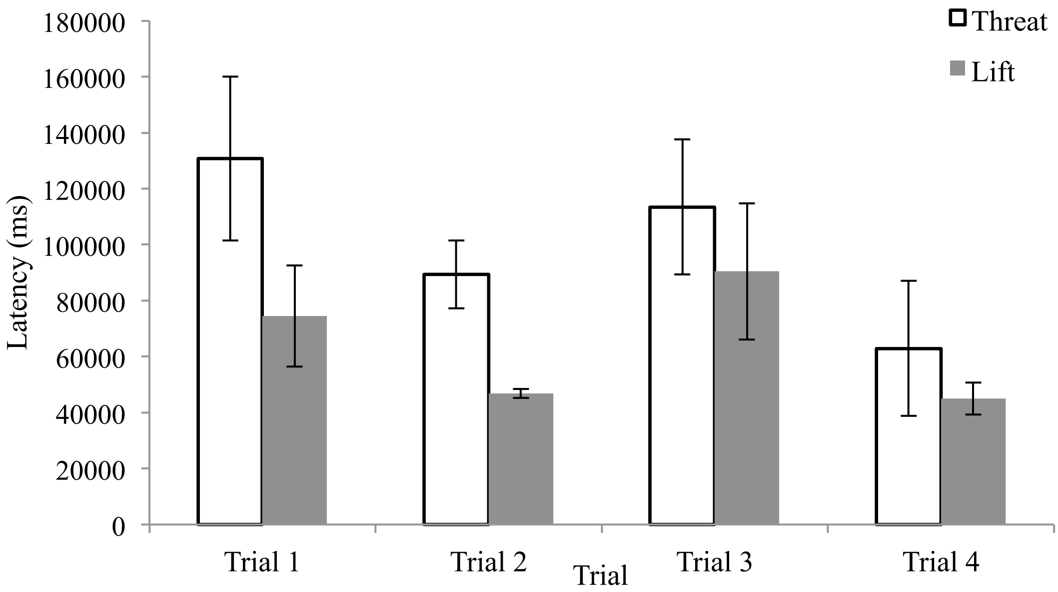


Figure 7.14. Mean latency recorded by male participants across the four trials. Male participants within Group Stereotype Lift recorded shorter latencies than males within Group Stereotype Threat. This suggests that the stereotype threat negatively influence latency. Error bars represent the estimated standard error of the mean.

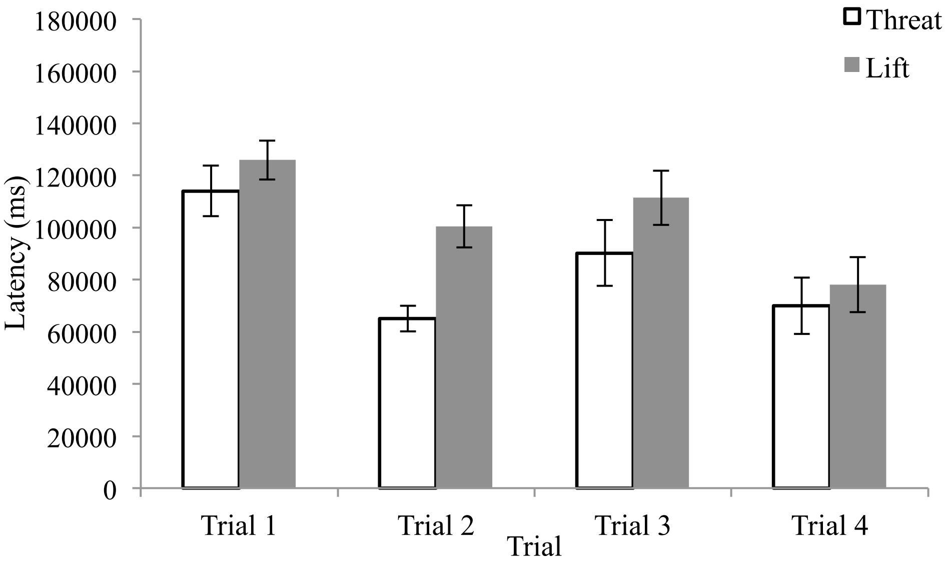


Figure 7.15. Mean latency recorded by female participants across the four trials. Unlike male participants, females within Group Stereotype Lift recorded greater latencies than females within Group Stereotype Threat. Performance does not appear to differ between the two groups to a significant extent however suggesting that female performance was not influenced as much by the presence of the stereotype manipulation. Error bars represent the estimated standard error of the mean.

Participants' latency was compared using a mixed design 4 Trial (Trial 1, Trial 2, Trial 3, Trial 4) x 2 Gender (Male/ Female) x 2 Condition (Stereotype Lift/ Stereotype Threat) ANOVA. Mauchly's test showed that the assumption of sphericity had been violated, $\chi2(5) = 19.78$, $p<.05$, as such the degrees of freedom were modified using the Greenhouse-Geisser estimates of sphericity, ($\varepsilon = .79$). A significant effect of trial was seen, $F(2, 95) = 10.95$, $p<.05$, $\eta_p^2 = .22$. Participants' latency significantly differed across the four trials. To examine where this difference lay, a series of bonferronii corrected paired samples *t*-tests were used (alpha value reduced to .001). These test revealed that there was a significant difference in participants latency between Trial 1 (M = 116682.95ms, SD = 43387.26) and Trial 2 (M = 80806.82ms, SD = 32831.86), $t(43)$ = 6.63, $p < .001$. Suggesting participant performance improved over initial training. No significant difference was seen in the time taken for participants to complete Trial 1 and Trial 3 (M = 102078.41ms, SD = 48337.02), $t(43)$ = 1.51, *ns*, or between Trial 2 and Trial 3, $t(43)$ = -2.54, *ns*. This suggests participants were still able to accurately navigate to the end of the maze once the instruction cues were removed. A significant difference was seen however between Trial 1 and Trial 4 (M = 69515.91, SD = 43576.27), $t(43)$ = 5.76, $p < .001$. A significant difference was also seen in participants latency between Trial 3 and Trial 4, $t(43)$ = 3.68, $p < .001$. This suggests that when participants were free to follow any route they wished, they were able to complete the trial with reduced latency.

No interactions were observed within this study based on latency between Trial and Condition $F<1$, *ns,* $\eta_p^2 = .01$, or Trial and Gender $F<1$, *ns,* $\eta_p^2 = .01$. No 3-way interaction was observed between Trial, Gender and Condition, $F<1$, *ns,* $\eta_p^2 = .02$. This suggests that the stereotype manipulation was insufficient to consistently impact participants' performance.

No main effect of Condition was observed $F<1$, *ns*, $\eta_p^2 = .02$, suggesting the stereotype manipulation did not consistently impact participants latency within the trials. No main effect of Gender was identified, $F(1, 40) = 2.20$, *ns*, $\eta_p^2 = .05$, males and females did not significantly differ in the time taken to complete the trials. A significant interaction was, however, observed between Condition and Gender, $F(1, 40) = 9.82$, $p < .05$, $\eta_p^2 = .20$. Post hoc comparisons using simple main effects demonstrated that there was a significant effect of Condition for male participants, $F(1, 40) = 8.20$, $p < .05$, males in Group Stereotype Lift recorded lower latency than males in Group Stereotype Threat.

There was, however, no effect of Condition for female participants, $F(1, 40) = 2.460$, *ns*. Female participants' latency was not affected by the presence of the stereotype manipulation. Furthermore a significant effect of Gender was observed within Group Stereotype Lift, with males recording significantly lower latency than female participants $F(1, 40) = 10.657$, $p > .05$. No effect of Gender was however seen within Group Stereotype Threat, $F(1, 40) = 1.362$, *ns*, trial latency did not significantly differ between males and females who were exposed to a stereotype threat. These results suggest that male, rather than female, participants were influenced by the presence of the stereotype manipulation.

Figure 7.16 and Figure 7.17 present the mean distance participants' travelled during the four trials, for males and females respectively. It can be seen from Figure 7.16 that male participants appear to travel further in Trial 3 than in trials 1 and 2 were instructions were provided. Male participants do appear to find a shorter route within Trial 4, travelling less distance within this trial compared to Trial 3. In contrast, Figure 7.17 suggests that the distance female participants travelled remained relatively constant between trials and conditions. Although it appears that both male and female participants in Group Stereotype Lift recorded less distance travelled, compared to Group Stereotype Threat, this does not appear to be a large effect.

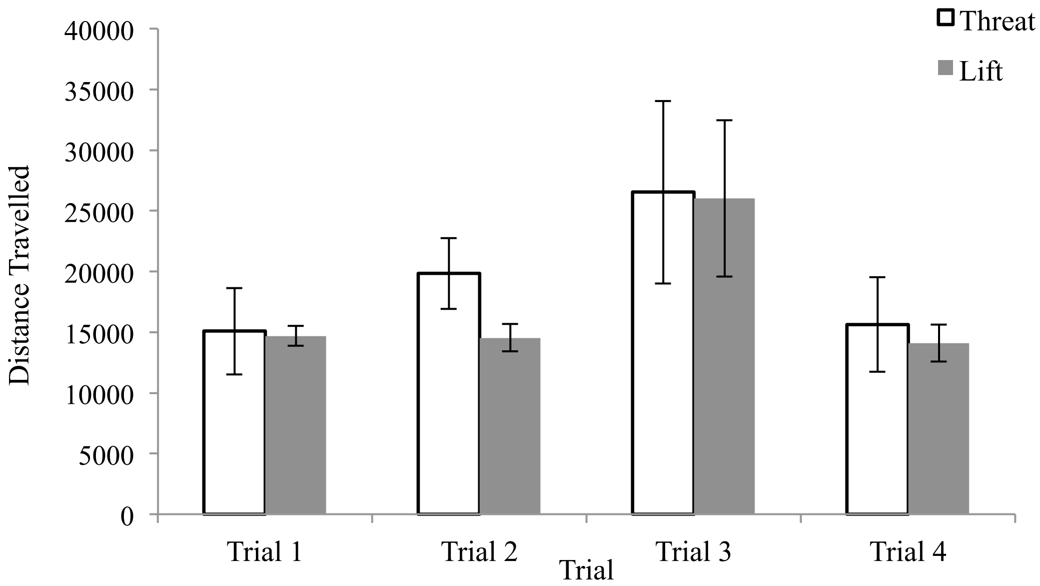


Figure 7.16. Mean distance travelled by male participants across the four trials. Male participants within Group Stereotype Lift recorded less distance travelled than males within Group Stereotype Threat, although this is not a large effect. It is noteworthy however to see that the distance travelled increases during Trial 3, suggesting that male participants were unable to retrace the previously experienced route. Distance travel falls however within Trial 4 suggesting male participants were aware of efficient routes within the maze. Error bars represent the estimated standard error of the mean.

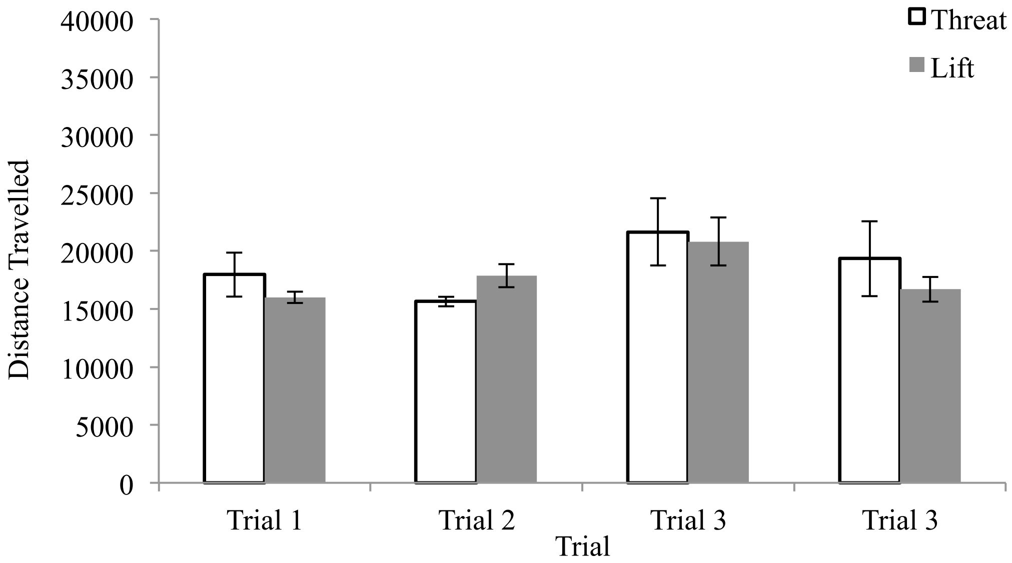


Figure 7.17. Mean distance travelled by female participants across the four trials. Unlike male participants, females recorded relatively consistent distant travelled across the four trials. Although it appears that female participants within Group Stereotype Lift recorded slightly less distance travelled, this does not appear to be a large effect. Error bars represent the estimated standard error of the mean.

Participants' distance travelled was compared using a mixed design 4 Trial (Trial 1, Trial 2, Trial 3, Trial 4) x 2 Gender (Male/ Female) x 2 Condition (Stereotype Lift/ Stereotype Threat) ANOVA. Mauchly's test showed that the assumption of sphericity had been violated, $\chi2(5) = 24.43$, $p<.05$, as such the degrees of freedom were modified using the Greenhouse-Geisser estimates of sphericity, ($\varepsilon= .71$). A significant effect of Trial was seen, $F(2, 86) = 6.71$, $p<.05$, $\eta_p^2 = .14$. The distance participants travelled across the four trials differed. To examine where this difference lay, a series of bonferronii corrected paired samples *t*-tests were used (alpha value reduced to .001). When the data was examined in this regard however, all comparisons failed to reach required statistical significance.

No main effect of Condition (F<1, *ns,* η_p^2 = .02) or Gender (F<1, *ns,* η_p^2 = .001) was observed based on distance travelled. This suggests that Group Stereotype Threat and Group Stereotype Lift did not differ on distance travelled. This also suggests that male and females did not differ on distance travelled within the maze. Furthermore, no significant interaction was observed between Condition and Gender, F<1, *ns,* η_p^2 = .004.

Whilst post hoc comparisons for the distance travelled main effect of Trial were not statistically significant, it is worth considering the trends within this data series. Of particular interest is why male participants distance travelled increased in Trial 3. The mean number of errors in Trial 3 for male participants in both Group Stereotype Threat and Stereotype Lift are presented Figure 7.18. Participants recorded an error each time they deviated from the taught route. Although participants within Group Stereotype Threat did record slightly higher mean number of errors compared to Group Stereotype Lift, no large group differences are observed between the two groups. Indeed, when errors within this trial are compared across groups using an independent samples t-test, no significant difference was observed, t < 1, *ns.* This suggests that group did not determine the number of errors made. It should be noted that two participants from Group Stereotype Threat were unable to navigate to the end of the maze during this trial suggesting that they had lost sense of where they were within the environment, see Figure 7.19. A similar finding was observed in one male participant within Group Stereotype Lift however. Based on the available data it would appear that the increase in distance travelled for male participants within Trial 3 was a consequence of these participants becoming lost and being unable to navigate to the end of the maze during this trial rather than as a demonstration of greater exploration. This suggests that these participants had not paid sufficient attention to the local and distal cues available within the maze, and were simply following the instruction cues during Trial 1 and Trial 2.

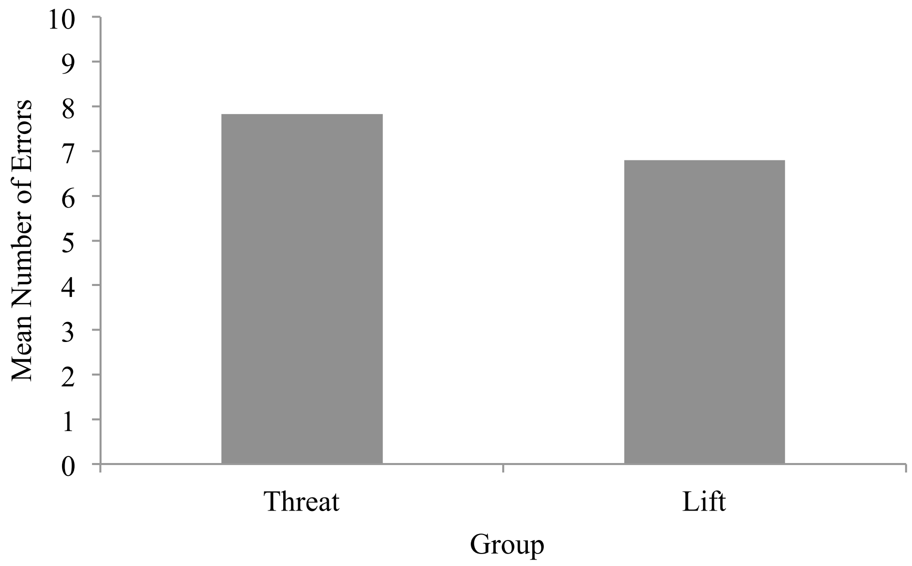


Figure 7.18. Mean number of errors made by male participants during Trial 3. Although males assigned to Group Stereotype Threat do record a higher number of errors, this is not a sizable effect.

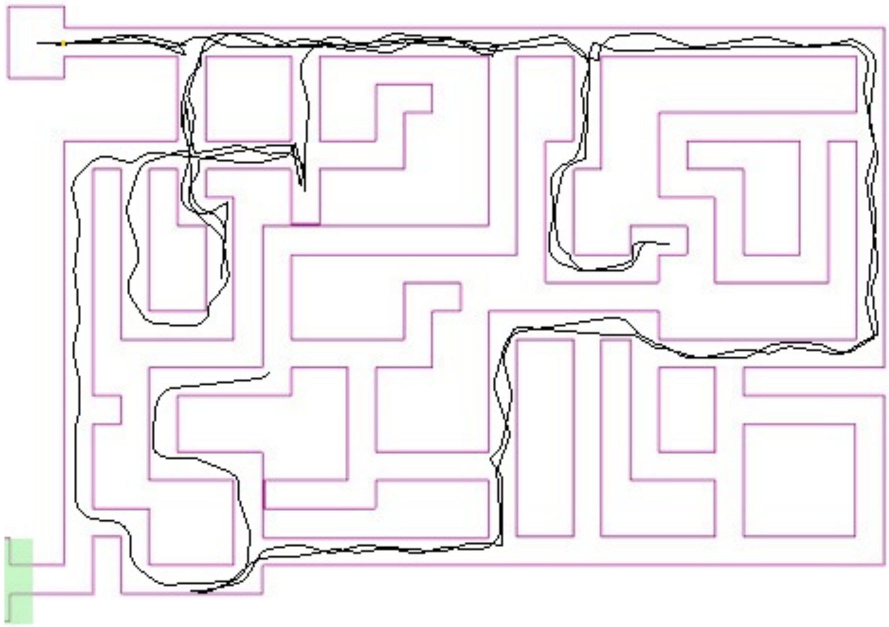


Figure 7.19. Route taken by one male participant from Group Stereotype Threat during Trial 3. As can be seen this participant is unable to accurately retrace the learnt route and never reached the end of the maze.

Although limited statistically significant results were observed within this study, the data did suggest that males were affected by the stereotype manipulation to a greater extent than female participants. Based on participants' latency, males within Group Stereotype Threat recorded greater latency than males within Group Stereotype Lift across all trials. In contrast, female participants' appeared largely unaffected by the manipulation; indeed, at least numerically, mean latency for female participants was unexpectedly lower within Group Stereotype Threat than Group Stereotype Lift. The limited number of male participants within this study however and the lack of a control group restricts the strength of conclusions which can be drawn.

Discussion

Overall trends within the current study, although limited, do support the findings identified previously within Experiment 6. Results suggest that males, but not females, were vulnerable to the stereotype manipulation. Males within Group Stereotype Lift recorded reduced latency compared to males within Group Stereotype Threat. This effect was consistent throughout the study. Furthermore, although no significant effects was observed regarding distance travelled, males within Group Stereotype Threat did travel greater distance within all trials and recorded a greater number of errors within Trial 3 than males within Group Stereotype Lift. Female participants in Group Stereotype Threat however demonstrated reduced latency compared to females within Group Stereotype Lift, with no trends emerging for distance travelled, suggesting that female participants were not as strongly influenced by the stereotype manipulation as male participants. A greater number of participants would be required to confirm these trends however.

One notable finding within this study was that the mean latency for males undergoing a stereotype threat did not significantly differ from female participants. Previous research has indicated that males are more accurate at learning novel routes and faster at navigating within virtual mazes (Moffat, Hampson & Hatzipantelis, 1998). Unlike males within Group Stereotype Lift, males within Group Stereotype Threat did not support this. This finding suggests that males were negatively influenced by the stereotype manipulation. The finding that males were affected by a stereotype manipulation supports the work of Hausmann et al., (2009) and Rosenthal et al. (2012).

This study did have two key limitations that should be addressed. The first limitation was that participants completed the study within a group setting. Although instructed to complete the study independently, all participants explored the same virtual maze. It is possible that participants may have seen the route which others were taking within the maze. Although steps were taken to overcome this limitation, for example by placing participants apart with a spare computer separating participants, it is not possible to suggest that the presence of others did not influence some navigational decisions. To overcome this, it would be necessary to repeat this study, but have participants individually visit a laboratory. This adaption was not possible using the recruitment methods employed within the current study, however does warrant future attention.

The second key limitation of this study was the number of male participants available within all groups. This study used an opportunity sample of college students visiting the university as part of an outreach event; as such the numbers of participants was beyond the experimenter's control. This is most apparent when considering that the planned control group was dropped from the current study due to a lack of male participants. When considering the experimental groups however, it is clear that males form the minority of participants ($n = 11$). A greater number of male participants may result in clearer differences between Group Stereotype Lift and Group Stereotype Threat, and support the differences observed within this study. This potential should be explored.

Conclusion

Results demonstrate that male participants were vulnerable to a spatial stereotype manipulation. Female performance, in contrast, was not influenced by the presence of the stereotype manipulation. When males were exposed to a stereotype threat, latency increased so that it was not only greater than males experiencing a stereotype lift, but also undistinguishable from female participants experiencing either a threat or lift. This finding is consistent with previous research indicating that males but not females are vulnerable to a spatial stereotype manipulation (Rosenthal et al., 2012).

General Conclusion

Results from Experiment 9 demonstrated that male but not female participants were vulnerable to stereotype manipulation. It was argued however that this may partially be a consequence of task difficulty, with female participants being unable to orient using the limited cues within the internal-facing rooms, and consequently female performance could not deteriorate further when participants were presented with a threat manipulation. Results of Experiment 10 however suggest it is possible to induce stereotype lift and threat for both male and female participants. Within this study, the colour band orientation cues were provided within the environment. Results suggested that stereotype threat disrupted participants' ability to form an association between external targets and the colour band cues.

Results of Experiment 11 were however more akin to the results of Experiment 9. Within Experiment 11, it was again seen that male, but not female, participants were vulnerable to the stereotype manipulation. Male participants exposed to a stereotype threat recorded greater latency than males exposed to a stereotype lift. In contrast, female participants showed no evidence that performance was influenced by the stereotype manipulation. This supports the findings of Hausmann et al. (2009) and Rosenthal et al. (2012). Results from Experiment 10 however could suggest that this may partially be a consequence of task difficulty and a floor effect in a task with well documented gender differences (Moffat, Hampson & Hatzipantelis, 1998).

Within unmodified environments, spatial stereotype manipulation appears to induce anxiety within male, but not female participants, influencing subsequent task performance. As females are higher on spatial anxiety than male participants (Lawton, 1994; Lawton & Kallai, 2002) the addition of further anxiety produced by the stereotype threat did not appear to influence performance. Future research should examine, within both active and passive spatial tasks, the extent to which this effect can be replicated.

Chapter 8

General Discussion

This thesis has explored the role of orientation within virtual nested environments and geovisualisations. Results suggest that participants are struggling to maintain orientation within a variety of complex virtual environments; however, it is also apparent that this difficulty can be reduced and orientation performance facilitated. The aim of this chapter is to highlight key findings and discuss the possible theoretical foundations of these findings. Potential approaches to overcoming these difficulties will also be explored. This chapter will also consider potential future avenues for research before highlighting the potential implications of this work.

Recorded Difficulties and Potential Solutions

Multiple Spatial Reference Frames

Results support work relating to the existence of multiple spatial reference frames and the difficulties in co-ordinating movement with respect to multiple frames when only one is available (Shelton & McNamara, 2001; Wang & Brockmole, 2003). Wang and Brockmole (2003) argue that spatial memory is stored as individual reference frames, organised hierarchically whereby smaller scale environments are stored at lower levels (Taylor & Tversky, 1992). As a consequence, understanding of the spatial layout of a room is stored within a separate reference frame to the spatial layout of a building, which in turn is a separate reference frame to the layout of a campus. Wang and Brockmole argue that this is an efficient method for storing spatial understanding; individuals are only required to track changes within one level of the environment at a time. Orienting in a nested environment however, results in disrupted understanding when individuals have to cross reference frames. By providing information linking multiple reference frames the difficulty in switching between them can be reduced.

Research within this thesis cannot discount the possibility that only one frame of reference is formed, based primarily within the external environment. Should this be the case, the orientation errors recorded in the internal unvisited room is high because participants have lost track of that reference. Presenting features, the colour band cues, within the internal unvisited room may have enabled participants to establish a frame of reference within the room, which in turn could be associated with the external frame. The better performance in the internal visited room suggested however that participants were able to develop an internal frame of reference. This internal frame was maintained by exploration as, evidenced by the difference in participants' performance between the visited and unvisited rooms. This difference was apparent even though participants could use the feature of the computer laboratory in both of the internal rooms. One approach to testing whether participants possessed a separate internal representation might be to ask them to face a target within the building rather than an external landmark target, for example the school office. By including internal targets, it would be possible to examine whether participants possess a single combined reference frame for the external and internal environment or multiple independent reference frames.

Experiments 3 - 10 examined orientation within a virtual nested environment. It was consistently found that participants could successfully orient toward a non-visible external target provided they could see an alternative landmark cue present in their external reference frame. In contrast, orientation error was significantly higher when participants lacked information which linked their position within the building to the external environment. The role of multiple spatial reference frames was also explored within geovisualisations. Whereas within Experiments 3 - 10 spatial reference frames can be addressed in terms of the internal and external aspects of the environment, within Experiments 1 – 2, each zoom layer within the geovisualisations can be thought of as an independent spatial reference frame, which participants are required to integrate to understand both their position within the geovisualisation and the location of the presented information.

This thesis also investigated ways to reconcile this difficulty and attempt to link participants spatial reference frames. Within Experiment 3, it was found that within the digital nested environment, the addition of a map was not sufficient to achieving this goal, supporting previous research (Sjolinder, Hook, Nilsson & Andersson, 2005). It was found, however, that the inclusion of colour band orienting cues lead to a significant reduction in orientation error particularly for the internal unvisited room (Experiments 4 – 6). Whilst the inclusion of the colour band cues facilitated orientation performance, why they were effective remained unclear. Experiment 7 examined whether the specific layout of the colour band cues (Sloman, 1996; Jara, Vila, & Maldonado, 2006), or their mere presence (Hall, 1994; Folk, Remington & Johnston, 1992) was responsible for improvements in orientation performance. Results indicated that the colour band cues were only effective when arranged whereby participants could easily associate a colour band cue with an external landmark target. For example when standing in the carpark participants would see a green band on the front of the building and when looking in the direction of the carpark within the building they would also see a green band. The green band was thus consistently paired with the carpark. On the other hand, if the green band was placed on all south facing walls, this made the green band a cardinal orienting cue. However, when participants were in the carpark they would see a blue cue on the exterior north facing wall. Thus the association between the carpark and the green band was not consistent. Performance in this condition was no better than Group Control. Experiment 7 suggests that the colour band cues were effective because they enabled participants to integrate their internal reference frame with their external reference frame via associating the colour bands with external cues rather than using the cues as cardinal orienting cues. By allowing participants to make this association, they were able to accurately orient.

Results from experiment 7 suggested that the colour band cues promoted accurate orientation as they became associated with external landmark cues. Experiment 8 investigated whether participants demonstrated a preference for using either the external landmark cues or the colour band cues. Results indicated that, where available, participants maintained a preference for using external landmark cues. When completing an orientation task, participants are active in their search for information which can directly link their reference frames. Interestingly, the presence of the colour band cues did appear to still influence participants when these were placed in contrast to the external cues. This suggests that any cues which can link participants multiple spatial reference frames will be used when completing an orientation task.

Experiment 1 examined participants' ability to orient and track object locations within geovisualisations, based on pre-recorded video tours. Geovisualisations are interactive data maps (MacEachren & Kraak, 2001) which users can explore using zoom and pan. As a user zooms into a geovisualisation the information which is displayed changes, new information and detail becomes available, due to the use of semantic zoom (Perlin & Fox, 1993). As the visible information within each layer of the geovisualisation is different, it is proposed that each zoom layer the user explores can act as a separate spatial reference frame. Results indicated that participants' struggled to remain oriented when they zoomed between the different layers of the geovisualisations and struggled to accurately track the location of the displayed data. Results were similar to those found in the control groups in Experiments 3 – 7 and highly reminiscent of Midtbø and Nordvic, (2007), who found that participants struggled to track a beacon within a series of dynamic map displays. Results suggest that participants are struggling to integrate the different layers of the geovisualisation into a coherent spatial representation, supporting the view that each layer within the geovisualisation can act as an independent spatial reference frame. Evidence from Experiment 2, whereby participants actively explored geovisualisations, supports this claim. Whilst participants were highly accurate when searching for consistent targets, for example a high crime street within a high crime area, accuracy fell when participants were required to search for inconsistent targets, for example a low crime street within a high crime area. This suggests that changing spatial reference frames not only impacts participants' ability to orient, but also their understanding of information. As demonstrated within Experiments 3 – 10, these results indicate that integrating multiple reference frames is challenging.

In addition to quantitative data on accuracy gathered within Experiments 1 - 2, qualitative data also suggests that participants found integrating information presented across multiple zoom layers a challenge. Within Experiment 1 participants made general comments regarding how the changing view between zoom levels made it difficult to track data within the geovisualisations. This was expanded within Experiment 2 whereby participants expressed difficulties they encountered using the geovisualisations. It was found that concerns over orientation were common, with participants commenting that they lost track of their position as they zoomed. Similar to Experiments 3 - 7, this suggests that participants struggle to integrate multiple spatial reference frames.

Although acknowledging that difficulties occur when using zoomable map interfaces is not novel (Harrower & Sheesley, 2007), results suggest that this problem is magnified within geovisualisations. Within Experiment 2, participants noted that data frequently obscured orientation cues such as road names and building markers. This suggests that approaches to make both the data and orientation cues clearer and independent may to be necessary to facilitate the use of geovisualisations. Harrower and Sheesley (2007) suggest that the inclusion of consistent and visible cues throughout all layers of digital maps may act to improve usability. Evidence from Experiments 4 – 7 suggest that this would be the case as, similar to the addition of the colour band cues within the virtual building, consistent cues could potentially allow users to better integrate the different map layers, and consequently their different reference frames, facilitating use.

Interactivity

Experiments 5 – 6 investigated whether interactivity were essential to participants' ability to orient within the model building. Results from Experiment 5 demonstrated that participants' orientation accuracy after viewing a passive video tour was highly similar to Experiment 2, where participants controlled their movement. Like Experiment 4, it was found that participants within Group Control were unable to successfully orient within the internal unvisited room. The inclusion of the colour band cues within Group Experimental, however, removed this difficulty, suggesting that providing cues linking participants' spatial reference frames was more important than participants directly controlling their movement. Results from Experiment 6 demonstrated that participants without familiarity of the campus could successfully orient following only passive exposure. Furthermore, the colour band orienting cues were also effective at reducing orientation error for these participants. This adds further evidence to the view that interactivity is not required to effectively orient within a virtual environment, supporting Wilson et al. (1997) and Booth et al. (2000).

Interactivity was also explored within geovisualisations. In Experiment 1, participants had no control over their movement; it was found that participants made considerable errors when interpreting the presented information. In addition to participants' inability to track the position of data within the geovisualisations, results suggested that participants were not aware of mistakes they made. This was demonstrated by participants indicating a preference for a geovisualisation which they were unable to accurately use. Overall results suggest that passive exposure limited participants' ability to accurately interpret information within geovisualisations. In contrast to Experiment 1, participants in Experiment 2 had full control of their movement. Results showed that participants were able to more accurately interpret information presented within the geovisualisations. This supports work highlighting the importance of interactivity when using geovisualisations (MacEachren & Kraak, 2001; Lloyd, Dykes & Radburn, 2007). Participants' accuracy did deteriorate however during inconsistent searches as discussed previously, highlighting that the integration of multiple spatial reference frames and the role interactivity may be correlated, with greater interactivity linked to a greater ability to integrate spatial information.

Experience

The influence of experience on orientation was examined in two ways, direct experience of a location and environmental familiarity. Within Experiments 3 – 10, direct experience was explored by investigating whether orientation error differed between rooms which had and had not been visited during acquisition. In addition, Experiment 6 examined the role of environmental familiarity to address whether participants unfamiliar with the campus environment could orient successfully within the virtual model.

Although early spatial updating studies suggest that idiothetic cues are essential to successful orientation (Rieser, 1989; Farrell & Robertson, 1998, Wraga, Creem-Regehr, & Proffitt, 2004), results from Experiments 3 – 10 support that the experience of exploring a virtual environment can be sufficient to enable participants to update their position and successfully orient, even without idiothetic cues (Riecke, Cunningham & Bulthoff, 2007; Wan, Wang & Crowell, 2009). Participants' recorded significantly lower orientation error within rooms which had been visited previously. This evidence suggests that experience of visiting a room allowed participants to incorporate the room position within their wider spatial understanding of the overall environment. This finding can be supported by neurological studies, indicating that virtual environments can activate the same brain regions associated with real world navigation and orientation. Evidence suggests that the hippocampus, particularly place cells, (O'Keefe & Dostrovsky, 1971) play a central role in enabling successful navigation and orientation. This is supported by evidence that damage to the hippocampus negatively impacts participants ability to complete spatial tasks, for example digitised Morris Watermaze tasks (Astur, Taylor, Mamelak, Philpott & Sutherland, 2002; Barkas, Henderson, Hamilton, Redhead & Gray, 2010). Virtual environments have also been used within animal studies, particularly using rodents. Holscher, Schnee, Dahmen, Setia and Mallot (2005) found that rats could be trained to navigate a virtual environment. Expanding this research, Harvey, Collman, Dombeck and Tank (2009) trained head restrained mice on a spherical treadmill to run a virtual maze provided by a toroidal (doughnut shaped) screen. As well as measuring the extent to which the mice could learn the maze, Harvey et al. (2005) measured hippocampal place cell activation as the mice ran the maze. They found that not only could the mice learn to run the virtual maze, but also that place cell activation was highly similar to that observed within real world maze tasks. This finding suggests that the visual exposure to the virtual environment still activated neurological functions associated with navigation and orienting, without the need for extensive idiothetic cues.

Experiment 6 also explored the role of experience, by investigating whether participants who were unfamiliar with the campus were able to orient within the virtual model and benefit from the colour band orienting cues. Although participants unfamiliar with the campus environment did not benefit from visiting individual rooms, it was found that participants provided with the colour band orienting cues were able to accurately orient. This suggests that participants without familiarity can benefit from cues linking their spatial reference frames. It is suggested that the lack of a main effect of visiting a location during acquisition within Experiment 6 is a direct consequence of participants' insufficient familiarity with the environment. This may be a consequence of participants unfamiliar with the campus environment focussing on external landmark cues during acquisition rather than incorporating their position within the building into their spatial array (Siegel & White, 1975; Montello, 1994). Overall, however, results indicate that familiarity can impact orientation performance, supporting research within real world environments (Thorndyke & Hayes-Roth, 1982).

Anxiety

The importance of psychological manipulations, specifically the impact of stereotype threat, was explored in Experiments 9 - 11. Whereas it was clear from Experiments 4 – 8 that orientation could be affected by environmental manipulation, performance was also shown to be vulnerable to psychological manipulation. Within Experiment 10, it was found that both genders were vulnerable to a stereotype threat manipulation. Both male and female participants recorded greater orientation error when presented with "You will do worse than opposite gender" stereotype threat manipulation compared to controls, informed that gender did not affect performance, and participants told “You will do better than the opposite gender”. It is theorised that the stereotype threat manipulation induced anxiety within participants (Steele & Aronson, 1995), disrupting performance. Anxiety has been explored within previous work relating to spatial abilities and wayfinding strategies (Lawton, 1994; Lawton & Kallai, 2002). Spatial anxiety is positively correlated with landmark based navigation strategies (Hund & Minarik, 2006; Lawton, 1994; Lawton & Kallai, 2002; Schmitz, 1999). Participants undergoing a stereotype threat experience greater anxiety, increasing their reliance on landmark cues. When landmark cues were unavailable, for example within the internal-facing rooms, participants’ ability to orient was impeded. The use of a landmark based strategy has, however, been found to be the preferred strategy for females (Sandstorm, Kaufman & Huettel, 1998; Schmitz, 1999), who were also negatively influenced by the stereotype threat. This suggests that the induced anxiety impacted performance beyond changing spatial strategies. It is suggested that the presence of the stereotype threat negatively impacted female participants’ ability to use the colour band orienting cues present within Experiment 10, leading to greater orientation error.

As results from Experiment 10 suggests that participants are vulnerable to stereotype manipulation, informing participants of a positive stereotype may potentially reduce anxiety and facilitate subsequent performance (Walton & Cohen, 2003).

Future Research Opportunities

There were several gaps within this research programme that offer intriguing avenues for future research. The three key areas which should be addressed are 1) the role of familiarity, 2) the limited participant demographic addressed, and 3) the role of individual differences. Each of these will be discussed in turn.

Familiarity

Familiarity is a key limitation which should be addressed. Most experiments investigating orientation within this thesis used an environment with which participants had a degree of familiarity, a virtual model of the University of Southampton campus and the Shackleton building. Previous research (Thorndyke & Hayes-Roth, 1982), has demonstrated that experience can influence orientation decisions. A key rationale of Experiment 6 was to investigate whether familiarity with the environment was essential for the colour band cues to be effective orientation aids. Within Experiment 6 it was found that unfamiliar participants also benefited from the inclusion of the colour band cues, however, they did not benefit from room level experience within the model, which those familiar with the environment did. In other words, participants unfamiliar with the campus environment did not record lower orientation error within rooms which they visited during the acquisition phases, compared to the unvisited trial rooms. It is unclear however whether this effect is a consequence of the passivity that was imposed within this experiment or as a consequence of familiarity. As such, an experiment whereby unfamiliar participants explore and orient within the model using a non-passive methodology is needed to explore this variable in greater depth. This warrants further attention. Should sufficient participants unfamiliar with the campus environment be recruited and similar effects recorded, it would add further support to the view that the colour band orientation cues are appropriate for use within additional contexts and alternative spatial environments. This is essential in demonstrating the generalisability of the results obtained within this work. Furthermore this research would directly build on

Experiment 6, allowing researchers to determine whether familiarity or passivity were crucial factors in participants' performance.

An alternative approach to addressing the issue of familiarity is implementing the same, or similar intervention, the colour band cues, within an unfamiliar spatial environment. It would then be possible to see whether a similar decrease in orientation error is achieved. Although not possible within the current research program due to time constraints, this approach would enable researchers to also examine the role of environmental familiarity on participants' ability to orient. By examining the role of environmental familiarity, using both unfamiliar participants and novel environments, the role familiarity plays in orientation accuracy will become clearer.

Limited Demographic

The majority of research completed within this thesis drew from a participant pool comprising largely of young female undergraduate students. There is evidence suggesting that age can negatively impact a variety of cognitive processes including spatial ability (Kausler, 1994). Driscoll, Hamilton, Yeob, Brooks and Sutherland (2005) explored the role of age and gender in active spatial learning, using a virtual Morris Watermaze task and the Vandenberg mental rotation task. They found that older individuals recorded significantly greater spatial deficits than younger individuals, a trend apparent for both males and females. In addition they found that a recorded male advantage in spatial tasks was apparent throughout the age span. Although Driscoll et al. argue that this suggests that persistent male advantage demonstrates that spatial abilities are independent from normal age related decline, it can be argued that such a difference persists if both male and female spatial abilities decline at a similar rate. For the purpose of the current thesis, the decline in spatial ability noted by Kausler (1994) and observed by Driscoll et al.

(2005), suggests that age is an important variable to consider within spatial tasks. How a different aged population would react to the manipulations administered within the current research is unclear and as such would make an ideal population to consider. This is especially important when considering that an older population would likely benefit the most from interventions to make digital spatial environments easier to use, both as a result of declining spatial abilities and less experience with virtual environments.

Role of Individual Differences

The role of gender has been explored within both previous work and briefly within this thesis. In comparison to males, females' orientation performance increased significantly due to the presence of the colour band orienting cues. This finding is consistent with evidence suggesting females are more reliant on available landmark cues (Lawton, 1994, Sandstrom et al., 1998) than males, who are more likely to utilise geometric and non-landmark based cues. Although the primary aim of research presented within this thesis was facilitating general performance, exploring individual differences other than gender for example spatial experience would be valuable.

Previous research has indicated that spatial experience plays a central role in determining spatial ability. Baenninger and Newcombe (1989) explored gender differences within spatial tasks, as a consequence of spatial experience rather than innate gender differences, within an extensive meta-analysis. They found a reliable effect of participation within spatial tasks and spatial ability. Participants with greater spatial experience recorded higher scores on tests of spatial ability, regardless of gender. Furthermore, they found that training prior to a spatial test improves spatial performance for both males and females, with no sign that gender influenced this effect. There has been growing evidence to suggest that experience using digital environments impacts performance within digital tasks. Feng, Spence and Pratt (2007) found that experience playing action video games dramatically improved participants' spatial abilities, after only 10 hours of training. Similar studies have shown that exposure to video games can improve spatial ability, for example mental rotation (Cherney, 2008), improved ability within visual search tasks (Dye, Green & Bavelier, 2009) and improved visual memory (Ferguson, Cruz & Rueda, 2008). Others studies in contrast have failed to identify a clear effect of video game exposure on spatial ability, and found no effect of video game training on spatial ability (Boot, Kramer, Simons, Fabiani & Gratton, 2008). Whilst other research, Richardson, Powers and Bousquet (2010), has found that exposure to video games improved participants spatial ability within virtual tasks, but not within the real world. This is counter to what would be predicted and the claims of Gentile (2010) and the findings of Wilson, Foreman and Tlauka (1997) who found evidence that spatial skills were transferable across real and virtual environments. Richardson et al. (2010) argues that *"Although transfer of spatial knowledge is possible and perhaps likely, fundamental differences in sensory experience between the two learning situations may preclude the general transfer of navigational skills"* (*p*557). When dealing with virtual representation of the real world however, the interplay between these variables is unclear, and warrants extensive attention. The role of experience with video games has potential to be an important variable when dealing with orientation within digital spatial environments and its impact should be carefully considered. Exploring the influence of spatial experience, specifically prior video game exposure and the transferability of spatial abilities between real and virtual environments would be intriguing avenues for further research.

Including a direct measure of spatial ability would have been a useful inclusion into this thesis, allowing for the researchers to correlate spatial ability specifically to participants' ability to orient and use geovisualisation. Mental rotation tasks, for example the Vandenberg-Kuse mental rotation test (1978), are frequently used to measure spatial ability; as Driscoll et al., (2005) argue *"rotated three-dimensional images is the gold standard for measuring spatial cognition in humans"* (*p*326). These measures were not included within this thesis as the primary aim was to investigate ways in which to facilitate population performance rather than explore the extent to which orientation performance was correlated with spatial ability. The relevance of mental rotation tasks such as the Vandenberg-Kuse mental rotation test (1978) have however been questioned when considering realistic spatial tasks and map based tasks (Golledge, Dougherty & Bell, 1995; Golledge & Stimson, 1997). Although a greater understanding of the correlation between spatial ability and orientation ability, both within virtual environments and geovisualisations would be beneficial, the aim of this thesis was not to untangle the direct link between these variables. Rather the aims of the thesis was to explore how users were engaging with the tools currently available to them, and begin to explore ways in which these interaction could be facilitated. Understanding the role of spatial ability may however be useful for the development of suitable targeted interventions. Work currently available does point to interesting interactions between spatial abilities and the use of visualisations. Hegarty and Kriz (2008) argued that the use of animation within visualisations may act as an especially useful tool to those with lower spatial ability. Hoffler, Sumfleth, and Leutner (2006) found a compensatory effect with animated visualisations but not for static visualisations. Lee (2007) found, in a study investigating learning regarding Boyles Gas laws, learners with low spatial ability benefited most from an enhanced visualisation. No significant differences were observed between visualisation type and participants with high spatial abilities, with participants high in spatial skills recording similar scores in both the control and the treatment condition. Participants with lower spatial abilities in contrast, recorded significant improvement within the animated visualisation, performing almost as well as participants with high spatial abilities. These studies indicate that spatial ability may be an important variable to consider not only with regards to digital environments but also visualisations. Although there is currently a lack of research regarding spatial ability and geovisualisations directly, this is a potentially rich research area to explore. Exploring the link between spatial ability and orientation accuracy may be of particular benefit when considering the passive acquisition studies. Participants' level of spatial ability may be linked to performance within these trials, and if similar results to Hoffler et al. (2006), Lee (2007) and Hegarty and Kriz (2008) are observed, it would be predicted that participants with lower spatial ability will benefit most from the inclusion of the colour band cues. This could be explored using a within subjects repeated measures design study.

Implications

Results within this research programme demonstrate that users are in need of support to fully utilise virtual spaces and geovisualisations. With the increasing number of digital environments and geovisualisations used within educational contexts, to support industry and as primary sources of information for a variety of tasks, steps must be taken to ensure that users are able to accurately interpret and benefit from the environments and information provided.

Fundamentally, it is hoped that facilitating performance within virtual environments can lead to the development of more effective training programmes for the use of real world spaces. It has been noted that real world environments are complex to navigate and orient within, with many individuals potentially benefiting from an available virtual exploration prior to their visit (Wilson, Foreman, & Stanton, 1997). This would be of primary advantage in buildings such as hospitals, which are complex environments which users are required to navigate. When considering these spaces it is also worth considering that many users of hospital environments may also suffer from impairment to their spatial abilities, potentially as a consequence of age related decline (Taillade et al., 2013), a result of neurological impairment or damage (Barkas, et al., 2010) or anxiety (Lawton & Kallai, 2002).

Results from this research have societal implications. Results indicate that participants' use of spatial environments can be facilitated. As digital environments become increasingly widespread, it is hoped that interactions with such environments can become easier. Within this thesis it is clear that such environments can be made easier to orient within, and, by extension, easier to interact with. Previous research has indicated that both spatial ability and spatial attention is improved as a result of the use of digital environments; for example video game play (Feng, Spence & Pratt, 2007; Ferguson, Cruz & Rueda, 2008, Spence & Feng, 2010).

This is key when considering that previous research has also indicated that spatial ability is tied to academic success, with individuals high in spatial ability recording greater success in STEM based disciplines (Sciences, Technology, Engineering and Mathematics) (Delgado & Prieto, 2004; Wai, Lubinski & Benbow, 2009). Hegarty and Kozhevnikov (1999) suggest that the correlation between mathematical performance and spatial ability is as high as .5. Rohde and Thompson (2007) found that spatial ability remained a significant predictor of mathematical ability even after controlling for general intelligence level and working memory. Unsurprisingly, and perhaps partially as a consequence of this correlation, of those working in STEM based careers, it is estimated that in the UK only 17% are female (House of Commons Science and Technology Committee, Women in scientific careers Report 2014).

Previous studies investigating potential interventions, either facilitating greater spatial skills or encouraging individuals to think of arithmetic within a spatial context has been demonstrated to be highly effective (Kucian et al., 2011). Facilitating greater use of digital environments, especially among females, may act as a potential approach to help encourage the acquisition of spatial, and by extension, mathematical abilities. If, as Feng, Spence and Pratt (2007) argue, that both spatial ability and performance within STEM based disciplines are supported by the same fundamental cognitive abilities, providing participants with greater exposure to either STEM based disciplines and/ or digital spatial environments could help boost these skills. The development of easier to use digital environments may also help reduce inherent selection bias (Green & Bavelier, 2003) in the use of digital environments, whereby males chose to interact with digital environments and females do not.

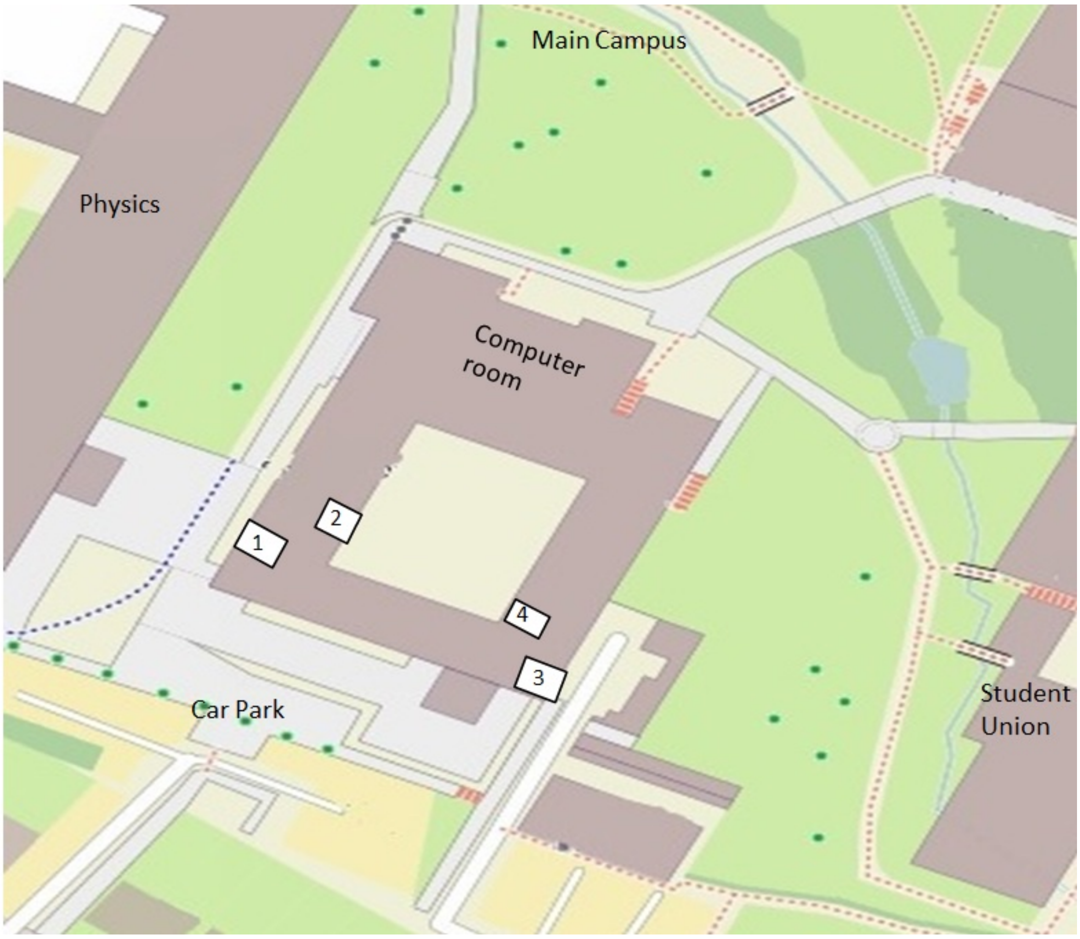
Concluding Remarks

Within this document, I have provided evidence demonstrating three key findings. Firstly, it is clear that individuals struggle to accurately orient within digital nested environments, secondly, the difficulty users experience when orienting within digital nested environments can be reduced by the inclusion of additional visual cues. Finally, it is clear that this difficulty extends beyond first person spatial environments, to include symbolised spatial environments, seen within geovisualisations. Taken together, these finding provide a mixed vision of the future for digital spatial environments and geovisualisations. On one hand, issues relating to participants difficulty in accurate orientation must be addressed in future software iterations. Users are struggling to interact with the tools available currently. However it is also clear that difficulties associated with orientation can be reduced with appropriate interventions, potentially making future systems easier to use and more accessible. Developers of virtual environments, including geovisualisations must show greater awareness of the challenges that users face in remaining oriented and offer support in making this fundamental task easier.

Appendices

Appendix 4.1.

Map of Campus layout



Appendix 4.2.

Route participants were advised to take during acquisition phase 1.

SHEET 1

Turn left to look at the **physics building**

Walk forward as you do you will see the **car park** on your left. Keep walking until you approach the entrance of the physics building.

Turn right and walk towards the **main campus**, follow this down until you reach the front of the building, the **physics building** is to your left.

When you have reached the end of the building turn right, you'll see the **university student union** straight ahead of you and to the left of this is the **main campus**.

Walk ahead until you reach the end of the building, if you look to your right you will see a set of stairs, although do not go this way.

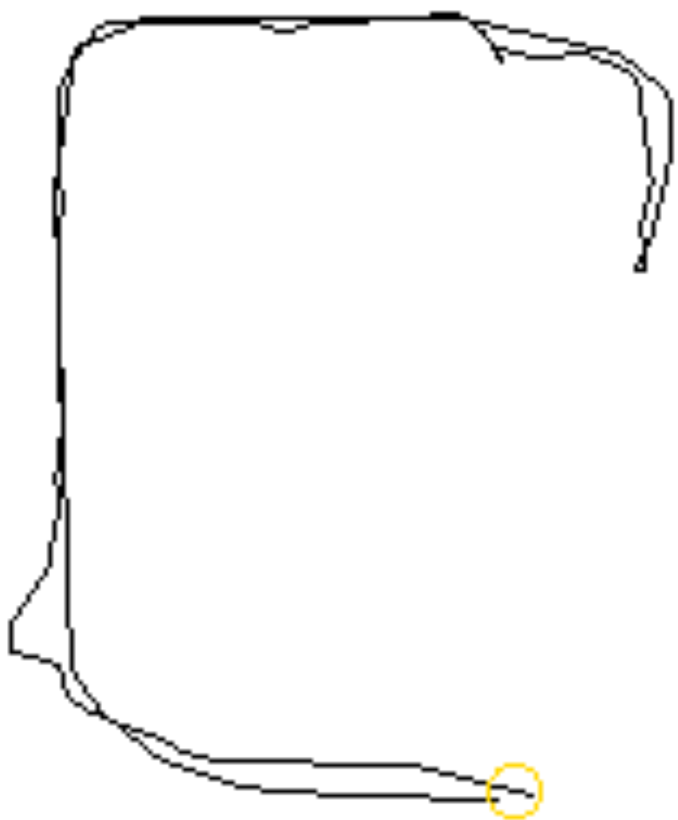
Familiarise yourself with the buildings and their layouts.

Retrace your steps and proceed to the main entrance, your initial starting location, for the purpose of this study, other entrances are unavailable.

When you're happy that you have reached your starting location, please inform the experimenter

Appendix 4.3.

Route taken during acquisition Phase 1. The yellow circle denotes participants start point. It can be seen that the participant explored the outside of the building before retracing their steps to the starting location.



Appendix 4.4.

Route participants were advised to take during acquisition phase 2.

SHEET 2

You will now explore the inside of the building. Again take as long as you need to familiarise yourself with the environment, where things are, where things relative to outside landmarks etc.

Again we recommend that you take the route shown to you whilst exploring this space to ensure that you see all what you need to see and do not get lost.

Enter the building and walk up the stairs to your left, walk up one flight of stairs so you're just outside the lift.

Turn right towards the large window.

At the window turn right and you will see a corridor, walk down this corridor. To your right you'll see an open door walk through it proceed down the corridor into the open room directly ahead.

Take a moment to look out of the windows in this room.

Leave the room and turn to your left, proceed down this corridor. Do not try and enter any of the other rooms.

Proceed past the door on the left to the very bottom of the corridor.

Turn to your right, walk through the large open the room (This should be the room you are physically in!).

Upon exiting the large room, turn to your left you will see large windows please take a moment to look out of these windows before turning to your right, head left, exiting the room.

You'll find yourself in a new corridor. Turn right and proceed down the corridor. As you do so one room on your right will be open, enter this room.

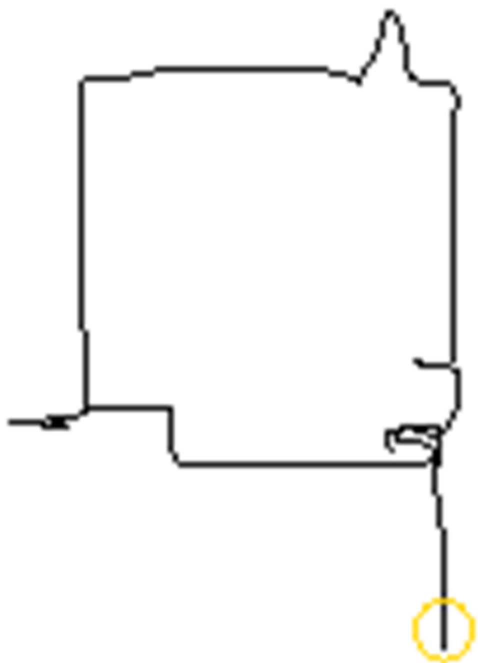
Again you will see large windows, please familiarise yourself with the view available.

Please leave this room and make your way to the stairs that you used when entering the building. Walk down the stairs and proceed to your starting location.

When you have reached the starting location please inform the experimenter

Appendix 4.5.

Route taken during acquisition phase 2. The yellow circle denotes participants start point. It can be seen that the participant explored the inside of the building before returning to the start location. The outcroppings represent rooms where the participant used windows to look out of the building.



Appendix 7.1.

Verbal Script to read to participants prior to the start of the study

I would like to ask you to participate in a short study looking at how individuals navigate virtual spaces. This study looks at what information people take from the environment to learn about where they are and routes they can take.

If you’re happy to take part, you will be asked to complete six short navigational tasks within a virtual maze.

If at any time whilst exploring the maze you start to feel dizzy or any feeling of discomfort, please stop and let me know, I will come and stop the study for you.

You are free to withdraw at any time from the research study. If you wish to withdraw at any time during the research study, please indicate this to the experimenter.

Your participation will aid in our understanding of how users interact with virtual environments.

Other than the researchers, no member of the university or members of the public will see or have access to the information which you provide today, including specific information regarding performance. All details and corresponding scores are saved on a password protected PC and will not be publically visible. Any formal write ups produced using the data generated within this research will not contain your name or any other identifying characteristics.

Appendix 7.2.

Debriefing speech Read after Participants complete the study

Thanks for completing that study

This research had 3 primary aims:-

1) To examine the use of cues whilst navigating a virtual environment.

2) To look at whether Stereotype threat (Feeling that we will be judged in terms of negative stereotypes and that we will inadvertently confirm these stereotypes through our behaviour) impacts navigational behaviour

3) To investigate the role of gender on participants navigational abilities.

Before we continue, I'd like to inform you all that this research did use deception.

To investigate the potential impact of different manipulations of stereotype threat it was necessary to inform you of potentially false gender differences prior to the start of the study.

I have debriefing sheets at the end of each row which has this debriefing information in writing for you to keep, including contact information for the ethics committee if you feel your ethical rights have been put at risk.

For the remainder of the session we are going to talk about gender differences in spatial learning, what these differences are, and what factors contribute to these differences.

Before I continue does anyone have any questions about the study they just completed?

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