# THE INFLUENCE OF SCREEN SIZE ON SPATIAL TASK PERFORMANCE

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March, 2013

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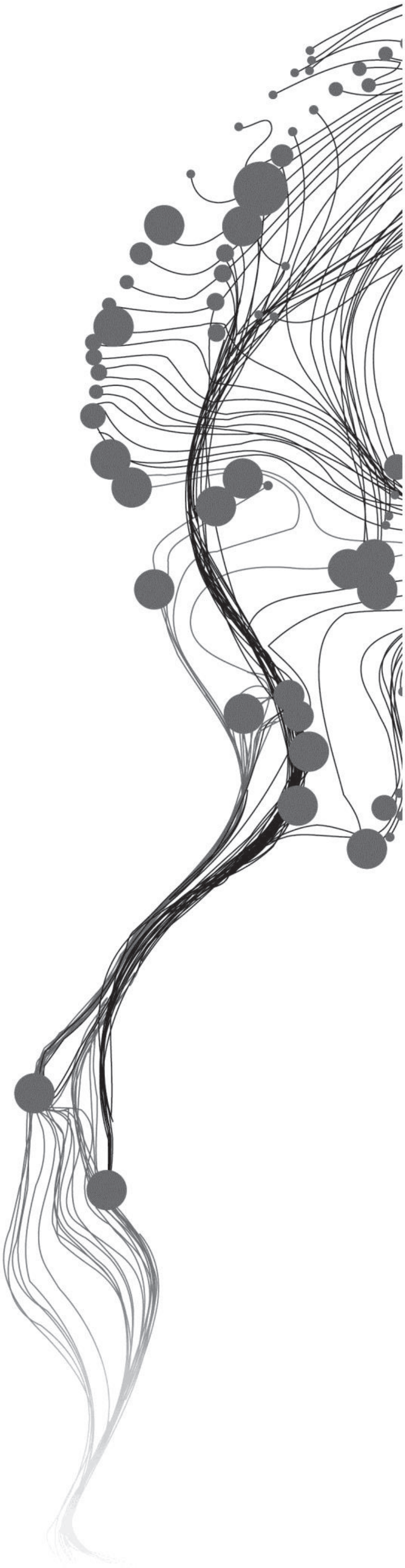

# THE INFLUENCE OF SCREEN SIZE ON SPATIAL TASK PERFORMANCE


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Enschede, The Netherlands, [March, 2013]



Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geo-information Processing

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# ABSTRACT

Rapid and widespread developments in display technology have made spatial information available in more formats and from more sources than ever before. New applications enable more sophisticated tasks, which in turn prompt increased use of a wider diversity of display devices. Due to this diversity, users can access many spatial information resources and services across a range of contexts in time and space. They are increasingly attempting to perform tasks that are typically done at the desktop on a variety of portable and accessible handheld display devices like tablets and smartphones. Despite the big improvements and advanced technical characteristics of such devices, some constraints still remain, like input methods and screen sizes. Screen size sets a limit on how much data can be comfortably presented at one time. When dealing with limited screens, the entire amount of available information on the map cannot be shown in a useful way at once or with equal focus. Displaying a map in its entirety typically provides only an overview without sufficient detail, while zoomed-in views offer more detail, but cause loss the overall context. Hence, users are required to navigate the map virtually by using zoom and pan functionalities that allow them to select the desired portion of space to be viewed. Understanding how user interact with digital maps across several display platforms, and how the interaction varies with different tasks and situations would help presenting appropriate methods of displaying spatial information on different devices, and would contribute knowledge to the study of human-computer interaction and spatial behaviour, information visualization, and map use and usability.

In order to explore how users' behave in using maps differ across different sizes of displays, a controlled lab experiment was designed and conducted for the purpose of investigating the impact of screen size on spatial task performance. Investigation took place in terms of: amount of interaction, task execution time, mental effort and subjective satisfaction and preference. Ten test persons executed typical common map reading tasks (locating, searching, comparing, and route planning) using a desktop 22 inches, a tablet 9.7 inches and a smartphone 3.5 inches. Several quantitative and qualitative methods were used in combination to supplement each other to collect data on user behaviour and some additional information. Those methods were: thinking aloud (audio recording), video recording and screen logging, interviews, and eye-tracking. Additionally, several questionnaires were administered to gather data on the TP's characteristic, satisfaction, preference and workload.

The findings indicate that screen size has impact on the presentation and exploration of spatial data. It has been noticed that different display devices do encourage different user behaviours when dealing with maps. Thus, screen size plays a role in spatial task performance. It can be concluded that desktop screens create the possibility for enhancing map interaction as increased display space allows for both greater context and detail in a single view. Overall, the TPs performed more effectively and efficiently on the larger displays, as evidenced by a reduction in virtual navigation (amount of interaction activities: zooming and panning) used to solve the tasks. Less zooming and panning on the desktop screen means that the TPs maintained a more stable sense of context and detail. Less zooming and panning also indicates less effort for manipulating the displayed map. That resulted in making the use of the larger display less stressful, and creates a better sense of confidence and satisfaction than the smaller ones. Eventually, the desktop was the favourite display for 6 TPs while the rest showed preference for the tablet. The touch screen in tablet was preferred over the smartphone because it is fairly easy to use, attractive and fulfils the TPs' requirements. Overall, it was surprising to find that the tablet was considered to be relatively equivalent to the desktop despite a relatively smaller screen. Most TPs indicated that using desktop and tablet was nearly equal (with the tablet coming close behind the desktop). Performance on the tablet was better than expected, many TPs enjoyed using it; they were content to have a fairly commensurate experience between tablet and desktop. On the other hand, and with screen size being a limiting factor, the majority of the TPs felt that they worked harder, performed poorer and were more frustrated when using the smartphone compared to the desktop and tablet.


*Key words:* Display size, interaction, mental effort, spatial tasks, overview, touch screen, details, performance, context.

# ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to all my committee members. My utmost gratitude goes to my supervisors: Dr. Corné van Elzakker and Ms Dr. Connie Blok for all their valuable critics and suggestions, insightful feedback, and expert guidance throughout the course of my research work, and above all, for their kindness, patience and moral support towards me.

I am indebted to all persons who spent their precious time and effort participating in my experiment.

I acknowledge the assistance Mr. Willy Kock has provided concerning the usability lab settings.

I heartily thank the Joint Japan/World Bank Graduate Scholarship Programme (JJ/WBGSP) for giving me the opportunity to further my studies and expand my horizons.

This pursuit was made possible through the endless care and understanding, continuous encouragement and motivation from all my loving family members. For that, I am forever grateful.

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# 1. INTRODUCTION

## 1.1. Background (Overview)

People often interact with several display devices depending on their current task and device capabilities. Dearman and Pierce (2008) found that users interact with as many as five personal devices and often have activities that span across many of them. Each device affords a different usage pattern based on its characteristics and context of use. For instance, typing and browsing for points of interest might be easier to do on a desktop/laptop than on a mobile device in the car , while following directions and turn-by-turn routing using a smartphone/personal digital assistant (PDA) is more helpful and suitable when one is on the move. People are rapidly utilizing their handheld devices to perform all kinds of tasks, such as reading news, examining reports, watching videos, seeking maps, and accessing bank accounts. Till recently, this could only be conveniently done on desktop or laptop computers. However, the presence of mobile computing devices in all forms and their use for seeking information is expected to continue expanding vastly. Therefore, research is necessary on the suitability of such devices for performing tasks, especially with respect to screen sizes that are substantially smaller than traditional displays.

Fast advancement of digital information and communication technologies (ICT) has changed the way we communicate, exchange information, and catch up on contents. Today, geographical digital tools (like virtual globes, web mapping services, GPS, etc.) are closely linked to computer-based communication processes, and (Geo-) ICT is extensively used in a wide range of different applications. Interest is rising on enabling geographic information to be effectively retrieved and used on multiple display devices, especially the mobile ones.

## 1.2. Research’s Problems And Motivations

Along with the advent of global computing comes the realization that in the near future, users will want to move seamlessly from one device to the next depending on task and/or context. This can be significantly complicated by substantial differences in device characteristics. Display size is shifting and means of interaction are changing to accommodate these shifts. While it is certainly the case that display devices' features, users' abilities and interaction means are improving, what is still unclear is to know which of these fundamentally affect spatial tasks performance.

This wider availability of the platforms / devices does not necessarily imply that the quality of the communicated spatial information as displayed on these platforms / devices remains the same. As cited in Aquino et al. (2010), different aspects may be affected by using different platforms/devices: usability (Abrahão et al., 2008; Seffah et al., 2006), portability (Vanderdonckt, 2008), task completion time (MacKay et al., 2004), screen size (Eisenstein et a1., 2001) and many others. Therefore, there is a need to investigate what variables may positively or negatively influence the process of retrieving information. This need becomes even more important when different user interfaces are produced for different platforms/devices while taking into account constraints imposed by these platforms/devices (e.g., limited screen size, reduced set of interaction capabilities).

Focus to date on information seeking on various mobile devices has yielded some information about behaviour patterns in different contexts, and about issues related to the interfaces. However, little is understood about how information seeking on such devices compares with the desktop in terms of display size and interaction techniques. Little has been done to identify the exact role of screen size in how, when and where interaction with display devices occurs, especially for the use of geo information. It is an aim of this work to help uncover some of the details related to such topics and make a small foundational contribution to that field of research.

The academic literature commonly asserts that as much as 80% of all information involves a geospatial component (Meeks and Dasgupta, 2004, as cited in Smith, 2011). Despite the extensiveness of geographic data in our daily lives, much is not yet understood about how it impacts and shapes information retrieval behaviours. The Horizon Report (Johnson, Levin, and Smith; 2009) identifies geospatial systems as a key transformative technology for society, predicting a world that will be "geo-everything" within two to three years' time frame. For that reason, there is a significant and timely need to develop a better understanding of human behaviour within geospatial information contexts.

Increasingly, users are looking for ways to access geographic information and perform more sophisticated types of tasks across computing platforms of varying display size and interaction techniques including: desktops/laptops, tablets, PDA's and smartphones. Lately, Google® has published a research report (*URL1*) on how consumers use different devices together and navigate the new multi-screen world. They set out to learn not just how much of media consumption happens on screens, but also how people use multiple devices together. One of the key insights is that 90% of people move between devices to accomplish their goals, whether that is on smartphones, desktop computers, tablets or PDA's. Choosing the appropriate display device/technology depends on a variety of factors, including: the tasks people are trying to accomplish, the environment in which they are interacting, the technology available, and the individuals involved. Both the task types and the required styles of interaction might affect the appropriateness of a given display configuration. Further knowledge about such issues would contribute to our understanding of the impact of display choice. Detailed insights into display factors provide researchers and users with vision to an appropriate selection of display technology and a better conception of the trade-offs involved in choosing one display device over another.

While much prior research in the past has investigated the utility of a given application or the usability of a device, a tool, an interface or a model, less work has been done looking at task performance and subjective satisfaction while using different display devices. Geographical tasks like locating, searching, comparing, and route planning which are now possible to perform on mobile devices are well studied at the desktop environment but not well studied yet in the smaller display contexts. Perceiving spatial information while reading a map varies from map to map and from user to user. Thus, understanding what strategies people may use in that context is essential. While some studies provide insight into the cognitive processes and strategies associated with specific map-reading tasks, many of these processes and strategies have yet to be identified and, more necessarily, understood. Further research is needed to investigate how maps are being used across display devices, and how effective those maps are in providing the required information in order to satisfy the user's needs. Moreover, it is important to determine when and how efficiency and effectiveness differ for spatial information seeking tasks across numerous display devices in popular use. Revealing such information could inform design strategies to provide a more adequate experience across the platforms.

Researchers have not thoroughly studied the influence of variation in display size on presenting and interpreting rich complex datasets like geographical maps. More research is required to inspect issues of user satisfaction and develop solutions that can facilitate the access to geo-information on a range of computing devices. The results from this comparative study will provide a useful reference for future investigations into using maps under different display conditions. Such results will serve as a baseline to guide the use of specific devices in specific settings as well as the selection of the right device for a given set of tasks.

## 1.3. The Research Objectives

As display technology continues to improve, there will be an increasing diversity in the available display form factors including different screen sizes and interaction tools/techniques. Empirical evaluation of how display attributes affect task performance can help designers understand the strengths and weaknesses of different display devices and provide guidance for effectively designing and developing display environments.

Primarily, this research aims to understand what barrier(s) screen size represents for the use of different computing environments (e.g., desktop, tablet and smartphone) to perform information seeking tasks, particularly spatial ones. The researches have proved in many cases that using larger screens is more advantageous. This research explores to what degree smaller screens are less effective and efficient in executing spatial tasks and how that should be counterbalanced to the user satisfaction in choosing a particular display device for particular context of use. Carrying out this research helps to determine the relation between spatial task performance and screen size factor, and to inspect issues of user satisfaction as they relate to using diverse display devices.

The main contribution of this work is the evaluation of user experience when viewing maps in three different platforms like: desktop, tablet, and smart phone. The findings of this study would open a window to a richer landscape of how multiple spatial tasks flow across multiple devices .A fundamental understanding of the impact of screen-size on user productivity, as an outcome of this research, would bring new insights into the requirements for systems and applications that support user activities, both on desktop computers and in the context of tasks that involves handheld mobile devices such as tablets and smartphones. Moreover, this research would provide important clues on feasibility knowledge about which screen sizes are best for executing certain spatial tasks. At the end of this work, both quantitative and qualitative recommendations are expected to be made about improving efficiency of spatial task performance across different display devices in order to successfully answer specific geographic questions a user might have, given particular map's purpose and context of use.

## 1.4. Research Questions

This study is interested in how people approach their geographic-related problems with a range of display devices. It strives to provide possible answers to questions that are broadly posed as follows:

**RQ1**: How can screen size and spatial tasks be defined?

**RQ2**: Which spatial tasks do users perform and which geographical questions do they want to answer when looking at maps displayed on different devices with varying screen sizes?

**RQ3**: Are there differences in the type and amount of interaction of the users with various screen sizes while they are trying to accomplish specific spatial tasks?

**RQ4**: How does screen size affect the type and amount of interaction, task execution time, and individual preference and satisfaction? In other words, does presenting maps on larger screens always mean a better comprehension of the geographic information and hence a better performance?

## 1.5. Research Hypotheses

In order to carry out this research, some hypotheses have been structured as follows:

**H1**: The use of larger displays over smaller ones will enhance the performance of similar spatial tasks, resulting in less task completion time. These benefits, however, may differ depending on the map purposes and task types. Previous researches have shown that tasks such as text reading and content retrieval are slower to do on small screens (Jones et al., 2003), so this also is expected to be the case for interpreting maps, especially considering the rich form of geographical data they present.

**H2**: Due to the better overview of the map the users may have on larger displays, they would be able to generate better strategies that help them perform in a better way because they would not be spending much time and effort on retrieving and analyzing the data, nor on manipulating and altering the view on the screen. In other words, it was assumed that task performance would be positively influenced by larger sizes of the screen on which maps are presented because users would have more data and context visible at once.

**H3**: The users may experience more difficulties executing tasks and making decisions while using maps in smaller-screen conditions. Consequently, they would show a preference for the desktop over the smaller displays because they think using bigger screens makes them feel less stressed, less frustrated and more confident and satisfied.

## 1.6. Thesis Structure (Outline)

The structure of this work is attempting to follow a logical sequence to attain the research objectives and answer its questions. Chapter 1 has stated the research's problems and outlined its hypotheses, goals and expected contribution. The remainder of this thesis is organized as follows:

- **Chapter 2: Literature Review**

This chapter acts as a starting-point that provides existing knowledge (about spatial tasks, screen properties and interaction techniques) which is needed to do this research. Moreover, this chapter covers a number of previous related studies and goes over their findings.

- **Chapter 3: Research Methodology**

  This chapter proposes a work plan and justifies the methods applied to tackle the research questions. A thorough description is illustrated about how data was collected using approaches like eye-tracking, think aloud protocol, and questionnaires.

- **Chapter 4: The Experiment‘s Design**

  Based on the available facilities in ITC, a lab experiment was designed and implemented in order to investigate the impact of screen size on spatial task performance. This chapter defines in details the experiment's set up, materials, variables and procedure.

- **Chapter 5: Results and Interpretation**

  In this chapter, and based on the lab experiment's results, the outcomes of qualitative and quantitative data analysis are presented and explained with focus on studying type and amount of interaction, task completion time , and user satisfaction.

- **Chapter 6: Discussion, Conclusions and Future work**

  The last chapter highlights the main achievements of this study and summarizes its findings with respect to the research’s questions and hypotheses posed in chapter 1. Later in the conclusion, a wrap up of the whole research is given, along with a scope for further work in the future.

# 2. LITERATURE REVIEW

## 2.1. Introduction

As mentioned in chapter 1, the main focus of the study in hand is to compare executing similar spatial tasks across three platforms to find out to what extent the performance of these tasks is influenced by the size of the display on which map are presented. This chapter is mostly devoted to literature review as it sheds light on some existing relevant studies. It forms the knowledge base needed to carry out this work as it discusses associated aspects including: screen size definition, spatial task classifications and interaction techniques, along with notations about spatial information, contexts of use and mobile devices.

## 2.2. Related (Previous) Work

### 2.2.1. Large Displays In Previous Studies

Several important studies show the benefits of large displays regarding task performance. Intuitively, one might think that a larger display would always help with performance over a smaller display. However, research has shown that larger displays help more with some tasks and data sets than with others, i.e., larger displays do not always improve performance for all tasks and datasets (Ball and North, 2005). Simmons and Manahan (1999), as cited in Czerwinski et al., (2003), examined the productivity for MicroSoft Office tasks (using Word, Excel, etc.) with four different monitor sizes: 15", 17", 19" and 21" diagonal viewing areas. Substantial productivity benefits were reported for the 21" monitor size in terms of task times and overall preference. Similarly, through another independent study, Czerwinski et al. (2003) conclusively revealed that there is a considerable increase in performance speed when using a larger screen compared to a 15" screen. Likewise, a research done at the University of Utah (*URL2*) shows that increasing the screen size could be one of the simplest ways of increasing productivity. Office workers were tested on three different screen sizes: 18", 20" and 24". The 24" screen enlarged the productivity with 50% for tasks like copying and pasting in Excel sheets and editing text documents. Large screen can also be obtained by putting several monitors together in a specific format or configuration. A prior research done by Truemper et al. (2008) has demonstrated productivity increases for users performing tasks on larger or multiple screens. Task success has been found to increase for tasks performed on 4 X 17" monitors vs. a single 17" monitor. In another related work, tasks were performed faster and with less workload while using 2 X 17" monitors over a single 17" monitor (Kang and Stasko, 2008).

Continuing with large displays, a study done by Yost et al (2007), found strong evidence that large displays with increased amounts of visual information do not reduce accuracy and potentially improve it for certain types of tasks. Recently, Kaptan and Göktürk (2011) have organized a study that evaluates the effect of physical display size and resolution on GUI (Graphical User Interface) designers' perception and the implementation of usability guidelines. In the user experiments, they focused on two basic tasks that users perform on computers almost every day: 1) reading and comprehension, 2) visual search and comparison. The results suggested that users perform better on larger displays for visual search and comparison tasks.

In the *geo-domain*, prior studies have qualitatively observed in detail user behaviour on large displays and they also quantitatively explored visual effects of large displays on the users' task performance. For example, a research done by Tan et al. (2003) reported that users were more effective in completing spatial orientation tasks (26% better) when they work on a larger display compared to a common desktop monitor. In their study, the use of a 76" wide by 57" tall projected wall monitor was compared to the use of an 18" desktop monitor. This improvement came solely from an increase in display size, as resolution was unchanged. As a continuation of this research, Tan et al. (2004) quantified benefits of physically large displays for individual users and explored how large displays affect spatial comprehension and performance while interacting with a virtual environment. They noticed that the participants performed better in the navigation tasks on larger displays. Although another variable, interactivity, supported the task performance, this effect was found to be statistically independent from the size of the display. In their first study, participants performed spatial orientation tasks involving static 2D scenes. A significant performance gain was observed on the large display. In the second study, they designed tasks to examine how display size affected path integration performance in interactive 3D virtual environments. Not surprisingly, the participants were more effective on the physically large display; they suggested that large displays may afford a greater sense of presence. Another study directed by Ball et al. (2005) used a map-based experiment to evaluate navigational performance. Results showed that users of a 3 x 3 monitor configuration (17" monitors, 3840 x 3024 pixels) outperformed those on a single monitor; search and route tracing tasks were performed twice as fast with 70% fewer mouse clicks on the multiple monitor display configuration.

Continuing in the geo-domain, in an article written by Jakobsen and Hornbæk (2011) titled:" Sizing up visualizations", they described a controlled experimentation to learn more about the usability of three classic interactive visualization techniques (focus+context, overview+detail, and zooming) across three sizes of display used by 19 participants who navigated 2D geographic maps to find specific locations, compare items, and follow routes. Results have indicated a strong relationship between display size and the mentioned visualization techniques. While the "overview+detail" technique worked the best for comparing items; "Focus+context" technique was relatively more difficult to use at a smaller display size. In their work, Jakobsen and Hornbæk define overview+detail as a visualization technique (i.e. an interface design with / 2 /windows on the display: one for details position, and a smaller one in the corner for an overview scoop). However, the thesis in hand defines getting an overview and looking for details as two fundamental spatial tasks that can be accomplished via interaction techniques (i.e. activities like zooming and panning).

With regards to the subjective preferences and individual satisfaction, despite the wide selection of screen sizes available, "devices with larger displays are more popular" according to a survey conducted by T-Mobile USA (*URL 3*). In cooperation with Kelton, T-Mobile polled more than 1,000 Americans over age 18 to find that 77% of respondents would prefer a mobile device (i.e. a cell phone) with a screen measuring 4.5 inches or larger. T-Mobile says the larger display makes "enjoying HD content and getting work done easier than ever". Supporting the same notion, a survey released from Strategy Analytics (*URL4*) found that people want their next phone to have a large screen so they can use it to easily browse the Internet and watch videos. The research organization showed American and British research participants several prototype phones with small and large screen sizes and different thicknesses. A vast majority, 90 %, preferred phones with bigger screen sizes than their current smartphones.

Supporting the fact that "screen size has emerged as a key differentiator for display device, and from an economical point of view, a research (*URL5*) performed by NPD (a provider of comprehensive consumer and retail information for a wide range of industries) found out that worldwide shipment for mobile display devices with screen size that ranges between 3.5-inch to 7-inch will decline up to 2016 whereas devices in the 7-inch to 8.5-inch range will represent a big growing sector in the market. In particular, tablets in the 9.7-inch to 11-inch will represent 65% of worldwide tablet shipments.

### 2.2.2. Small Displays In Previous Studies

Along with interest in larger displays, significant emphasis in recent years has been placed on small displays and their strengths and weaknesses. As cited in Chae and Kim (2004), a considerable research has been done on the usability of small screens (Duchnicky and Kolers 1983; Dillon et al. 1990; Han and Kwahk 1994; Jones et al. 1999; Kim and Albers 2001). Particularly, researchers have been interested in the question of information presentation: How one can display information effectively on screens far smaller than conventional computer screens?. Studies investigating the effects of small displays have indicated that reduced screen size is closely related to various user behaviours, including navigation, searching, and browsing (Dillon et al. 1990). Clegg et al. (2006) conducted a study of digital geological mapping using a Global Positioning System (GPS) on a PDA versus a Tablet. While the PDA proved convenient for remote mapping, the Tablet outperformed the PDA in most tasks. Thus, small display and limited processing power were considered to be the significant inhibiting factors.

Shreshtha (2007) contributed an important piece of baseline knowledge on the performance of similar tasks between a desktop and a mobile phone. Starting-points in the study included no prior experience with the mobile device, and device order presentation was the same for every participant (i.e. desktop first then mobile). Though the tasks were monitoring information and checking and sending email, results showed that of the total time participants spent completing the tasks, 80% was spent navigating on the mobile versus 20% on the desktop; which indicating that limited screen demanded more interaction from the participants to complete the tasks.

While early studies focused on issues of adoption and usability, more recent studies have been emerging attempt to address direct comparisons of specific features between or across a variety of devices. In her PhD dissertation, Marcial (2012) examined comparative task execution times for searching tasks performed by 29 users under three different conditions: varying screen sizes (desktop, tablet, smartphone), varying interaction devices (mouse + keyboard, touchscreen), and varying types of search task (within document, known item, exploratory). The findings of her research revealed that the single most important factor affecting task performance across task types and display devices is screen size. Based on her results, executing the three types of search tasks using the smartphone was more 'time-consuming' compared to using a desktop computer. Additionally, she found out that the advent of more intuitive and appealing interaction through touch-technology has bridged an important gap for task performance on the small screen devices. As she stated, the biggest contribution of her study overall is the finding that the tablet was considered to be relatively equivalent to the desktop in nearly every comparison, despite a slightly smaller screen. However, the main limitation of the tablet appeared to be text entry on the virtual keyboard.

Whereas these up mentioned studies concentrated mainly on the dynamic transformation of text content, lists and forms embedded in web pages for access on a range of devices from desktop to handheld, this study in hand focuses on the transmission of spatial data (specifically geographic maps). This study is building on the previous research done on display variables with main focus on the potential impact of screen size on map comprehension. Particularly, this study is designed to reveal more on the spatial task performance with varying display devices, while employing the lessons learned from the earlier work.

### 2.3. Mobile Devices

Now that mapping software and GIS functionalities are available for handheld computers, and commercial enterprises are offering maps for use on PDAs and cell phones, digital maps are and will increasingly be used on mobile display devices in mobile contexts. Under the term mobile device we understand any device designed for use in mobile situations (Marcial, 2012). As stated by Reichenbacher (2004), Mobile device is a wide term covering information terminals, information appliances, PDA's, portable computers (laptops), cell phones etc. . Smartphones can be seen as the next generation of PDAs since they incorporate all their features but with significant improvements in screen resolution, battery life, memory size and graphics processing. Tablets can be described as lightweight note-book computers that have touch sensitive displays for input rather than a standard keyboard. All these devices are very different in many aspects from each other. These new smartphones and tablets, which are small enough to fit in a pocket or backpack, hold a massive amount of computing power. Information on such devices is available at a simple touch or finger flick and many users use these devices to access all sorts of data or services and perform all types of tasks that are normally reserved for desktop systems, such as video conferencing, watching movies and reading maps.

Mobile devices allow the users to access geo-referenced information in real time, anywhere and anytime, in a dynamic and flexible way (Burigat and Chittaro, 2007). Nowadays, mobile devices are developed enough to display maps, images, web pages, and many other large complex data spaces. In addition to new technological capabilities of them, all these devices have different types of users with different preferences and purposes such as navigation, tracking and data acquisition. Making use of increasingly powerful and affordable mobile devices has resulted in the foundation of mobile geographical information systems. Thus, map-based applications and services are no longer limited to the desktop domain. Clarke (2001) indicated that in the coming era cartographic data is not desktop computers centric but would be available on mobile systems as well. Reichenbacher (2004) also stated that “the dissemination of digital geospatial data is no longer bounded by the desktop platforms. Rather, it is available now on mobile devices such as PDAs and cell phones”. The usability of mobile maps largely depends on the interaction with them, the interaction with the device itself, and rendering of the information on the maps (Looije et al., 2007). One of the most complex steps in the process of designing proper geographic visualizations for the mobile setting is laying out the information on the available screen space. It is broadly recognized that the main weakness of mobile devices is directly related to their main strength: small display size. Normally, the small screen on mobile devices puts limitations on the ability of transmitting and visualizing spatial information, because it is not possible to display the level of details generally used in paper or digital maps for desktop setting. From a geographic point of view, Cartwright et al. (2001) emphasized that the main challenges with mobile devices are : to identify the ways in which geospatial interfaces should be different from other interfaces, how geo-visualization interfaces should be created or adapted for such new and emerging devices, what are the most appropriate interaction methods for different users and applications, and how users with different expertise interact with the tools of the geospatial interface.

Looije et al., (2007) pointed out a number of usability problems mobile devices present; those problems could be divided into: technical, environmental, and social. Technical challenges, such as network connectivity, processing speed, power supply, the screen's colour range and storage capacity are improving at a very fast pace with advancement in technology while other technical limitations such as the display size still last and will remain even in the future. The social challenges include privacy, comfort, and personalization. The environmental challenges are much more puzzling and very diverse, they include changing temperature, light, level of noise and distractions, mobility of the user, and competition for attention of other concurrent activities of the user. Mobile devices are often used in outdoor situations, which means that their visualization should be totally different compared to office desktops at indoor situations . And not only the visualization, but also the information needed and used in the mobile context, should be distinctly different; the user in an outdoor environment has less time and limited input facilities to interact with the map in contrary to desktop computers (Nagi, 2004). As indicated by Looije et al., (2007), the mobile device usability is very much influenced by the different activity modes of the user and the ever changing environment. For instance, a laptop can be used in different environments but the user will not be walking, whereas the environment in which a mobile device (like a smartphone) is used can be changing all the time influencing the mental workload of the user who could be sitting, standing, or walking. Chae and Kim (2004) argued that the usability problems faced when using mobile devices are worsened by the nature of the tasks that users characteristically perform on them. Users frequently face situations in which they must access complex information at the point of need under time pressure, as for instance, when a user wishes to find the nearest hospital to his current location. In such cases, unless the user can retrieve the exact information he/she wants immediately, he/she cannot gain the full benefits of the mobile device (i.e., portability and instant accessibility).

Inherent in mobile devices design are two fundamental and interconnected constraints: small display size (Brewster, 2002, cited in Mountain and Macfarlane, 2007) and, correspondingly, reduced interaction between user and device due to more constrained input mechanisms and the distractions of the outside world (Passani, 2002, cited in Mountain and Macfarlane, 2007). Ostrem (2003) spotted a distinct difference in usage behaviour between desktop and handheld mobile device. With desktop, usage is characterized by few, long sessions, as opposed to handheld usage which is characterized by short, multiple, task-focused sessions, and these tasks are often of a fundamentally geographic nature such as routing and searching around one's location (Kjeldskov, 2002). What is more, Burigat and Chittaro (2007) stated that Input peripherals of mobile devices heavily constrain their usage. For example, keyboards (either physical or virtual) are limited in size and/or number of keys, making it difficult to manually insert data. The restricted means of interaction on mobile devices make it quite difficult for the users to perform tasks while they explore large information spaces like maps that do not fit on a single small screen, unless appropriate techniques and functionalities to simplify the exploration are provided.

## 2.4. Interaction Techniques

A major portion of usability testing is the Human-Computer Interaction (HCI); "the study of how people interact with computer technology and how to make this interaction effective" (Battleson et al. 2001). The user's ability to explore data interactively by rearranging it in different ways is one of the key stages in the data visualization process. Maps, or spatial information presented to the user through a digital interface, facilitate the goal-oriented activities (Dillemuth, 2005). Therefore, modelling user interaction by determining the activities for which maps are used, the way they are used and in what context, is considered an important step towards realizing map representations that are effectively tailored to the user (Dransch, 2001, cited in Dillemuth, 2005).

When the provided information is larger than the available viewing space, users need an access to details in order to do the exploration of large information spaces efficiently (Burigat et al., 2008). A typical approach to face this issue is to offer several common techniques and mechanisms (like scrolling, panning and zooming) which assist relevant access to content. When users interact with digital maps, they can select (and change) the portion of space to be visualized by panning and zooming. Those two operations are fundamental for the user's geographical navigation: zoom operation to get more detail and pan operation to move the field of view (Frank and Timpf, 1994). Zooming is defined as "the process of magnifying or reducing the scale of a map displayed on the monitor." Panning is defined as "the process of changing the position at which the view is displayed, without modifying the scale" (European Commission, 1998, cited in You et al., 2007). In other words, panning changes the area of the information space that is visible, whereas zooming changes the scale at which the information space is viewed. The zooming function allows increasing or decreasing the size of the visible portion of map (Gutwin and Fedak, 2004). It is necessary any time the user wishes to change either the visible range of data on the screen or its detail (Timpf and Devogele, 1997). On the other hand, panning function allows users to drag the map in any direction without any constraint to the movement. Such functionalities provide an intuitive and hierarchical structure that makes it easy to find and read the desired information.

Due to the screen-space limitations in some display devices, various interaction approaches and strategies have been developed to present the available data to the users in a more manageable form. Based on Shneiderman's mantra for visualization: "overview first, zoom and filter, then details on demand" (Shneiderman, 1996), most of these approaches require the user to first select an area of focus before indicating (via suitable interaction with the interface) which further details are requested. Ball (2006) defined "overview" as the amount of space one can see at once. The further one is able to zoom out, the more of an overview one is able to see. "Details" on the other hand are pieces that form part of the whole. A detail can be an attribute or piece of information. Details about a map might include the name of cities or roads. As one zooms out, one cannot see as much detail and small roads might disappear.

When users need to see more detail, they lose the overall context; however, if they view the entire coverage area, they lose access to fine details. To overcome this limitation of display size, panning and zooming functions are essential for virtual navigation (Slocum et al. 2005, cited in Luebbering, 2008). These functions allow users to capture desired coverage area and scale, providing the ability to quickly cycle back and forth between the two for comparison (Luebbering, 2008). Consequently, using such interaction techniques may cause a serial of separations between context and detail information. Such temporal separations, however, make it hard for users to focus on the visualization details while keeping track of the overall context. Hence, frequent panning and zooming have major implications on map comprehension. Panning operation at a large scale creates a loss of context, as the entire map is not visible, while zooming out to obtain the full context alters the scale and results in a loss of detail (Brown, 1993, cited in Luebbering, 2008).

### 2.5. Display Device Characteristics

Display technology has the power to change the way data is presented, perceived, and analysed. As it continues to improve, there will be an increasing diversity in the available display forms and sizes. Marcial (2012) remarked several key factors that have played roles in display development over time: technological advancements (e.g. Cathode Ray Tube 'CRT' versus Liquid Crystal Display 'LCD'; black and white versus colour), size (small versus large) and human visual capabilities / limitations (visual acuity and cognition; mobility and distraction; field of view). Due to changes in the cost of the underlying technology (LCD, CRT, plasma, etc.) and subsequent advancements in computing devices, displays today cover a whole range of types, sizes and functionalities. Though devices with nearly every possible size of display exist in the computing field, Marcial (2012) argued that some small displays are beginning to approximate the quality of more traditional desktop and laptop displays. Hence, display variations for use in mobile phones, PDAs and tablets have grown most significantly in the recent years. From a technical standpoint, there are numbers of key characteristics of the display that affect its visualization capabilities. Table 2-1 lists some of those characteristics.

| Display Characteristics | Description |
|---|---|
| Size | Measured in inches of the diagonal viewing area<br>(e.g. 17 inches)<br>*(URL 6)* |
| Pixel Density | Measured in the amount of pixels per inch<br>(e.g. 96 DPI -Dots Per Inch)<br>*(URL 7)* |
| Resolution | Measured in a horizontal multiplied by a vertical pixel count<br>(e.g. 1600 x 1200)<br>*(URL 8, URL 12)* |
| Brightness | Measures the amount of light emitted by the display<br>(in candelas per square meter)<br>*(URL 9)* |
| Contrast | Measured as the luminance ratio between the brightest and darkest colour (e.g. 700:1)<br>*(URL 10)* |
| Viewing Angle | Measured as the angle (horizontal and vertical) from which a display can be viewed with acceptable performance<br>*(URL 11)* |
| Bezels | The frames that surround the actual display screens |
| Display Technology | The technology used to create the display<br>(e.g. LCD, Plasma) |
| Form Factor | The physical arrangement and form of the display<br>(e.g. nine 17" monitors formed as 3x3) |

**Table 2-1 Display Characteristics**

Wei et al. (2000) declared that both physical size and resolution of the display play a major role in determining how much information can or should be displayed on a screen. A definition for the screen size can be expressed based on its resolution. A Related feature is the pixel density of the display. Together, size and density describe total resolution. Resolution defines the number of pixels a display element contains expressed in the horizontal and vertical directions (*URL 8*). In other words, display resolution refers to the total number of pixels available on the screen and this number determines how much information can be presented on that screen. The higher resolution (number of pixels) a screen has, the more information it can display at once. The Dots per Inch (DPI) measure refers to pixel density and it is screen-size dependent. A higher DPI means a greater number of pixels (per inch), implying that a greater amount of details can be shown. For example, a 17" display at 640 x 480 pixels resolution has a much higher DPI (typically 96 DPI) than a wall-sized display with the same 640x480 pixels resolution (*URL 8, URL 12*). A pixel can have 1 dot, or 4 dots or 8 dots...etc. So DPI measures how much information a pixel can display. The more dots per inch (which means the more dots per pixel too), the clearer/sharper, more focused and less blurry the image on the screen will be. Another related feature that depends on the resolution and the physical dimensions of the display element is sharpness. The same resolution will look sharper on a smaller display element and progressively lose sharpness on larger displays since the same amount of pixels is being spread out over a larger area (*URL 8, URL 12*). To sum up, screen resolution is determined by pixels. Pixels measure how much information a screen/monitor can display at a given time. DPI measures the physical clarity of each pixel. The effect of DPI simply makes things easier or harder to see/read by giving them more or less definition.
Low Resolution = Fewer data items visible or data items have less details
High Resolution = more data items visible or data items have more details

Later on at the experiment of this study, the physical screen size (measured in inches of the diagonal viewing area) is considered as the changing variable among the three selected devices: desktop, tablet and smartphone. As a direct result of changing the physical screen size, the screen resolution among those three devices changes as well (see Table 4-1 for details on the specifications of the three selected devices). However, this study is taking into account only the variation in the physical screen size (i.e. screen resolution and pixel density were overlooked).

## 2.6. Spatial Information

The combination of current computer interfaces and the web has led to highly interactive and widely distributed spatial information. The most common and effective means to communicate spatial information are maps (Kraak, 2002). While the computer has increased communication with maps, the web has improved their distribution. The World Wide Web (www) is a major medium for the dissemination of maps and it has a great potential for further growth due to the advantages of accessibility and actuality. Kraak (2001) defined a web map as a service on the Internet that enables users to search and browse geographic information such as locations and routes. Web maps have become popular on the web due to their convenience, low cost, and dynamic characteristics. Van Elzakker (2001) proposed modes of using web maps as: to explore, to analyse, to synthesize, and to present. Maps on the web have multiple purposes for providing up-to-date and accurate information. They present useful ways in giving insight into, and overview of spatial patterns, relationships and trends. Web maps can manage spatial data dynamically and display it flexibly through the interaction with the users. An interactive web map consists of several functions on the operational interfaces where scroll, pan and zoom are the most frequently used (you et al., 2009). Maps with this kind of functions are the standard these days in the big online mapping services like Google, Yahoo, MapQuest, etc.

Technological developments have brought changes to the way geographical data are acquired, processed, and distributed to the user. Given the fact that geospatial applications incorporate a variety of multimedia and geographic data is typically hyperlinked and extraordinarily rich with respect to the number and types of attributes that can be associated with geo-locations, showing a map with the right level of detail is very vital for the usage of that map. Looije et Al. (2007) indicated that the preferred level of detail is very dependent on the user needs and preferences and the current state of the user. For example, when the user is tired less information can be processed and the level of detail should be lower to keep the map usable. The preferred level of detail is dependent on the amount of information in the map (Bozkurt et al., 2005, cited in Looije et al., 2007). For instance , more details are required in a city than in a rural area. Their study's outcome indicated that the amount of information in reality should be considered while determining the level of detail on the maps.

At present, the possibility of using geospatial data on-the-go is increasing rapidly. While various kinds of maps and other geospatial content can be found on the Internet today, and with the vast evolution of the mobile Internet, these geospatial data cannot only be retrieved from traditional display devices like desktops computers, but also from mobile devices as well such as smart phones and PDAs. Substantial added value for maps on mobile devices is given by mobility and interactivity (e.g., location-awareness, and adaptation to user's interests and needs). Reichenbacher (2004) stated that "The emergence of mobile computing and wireless devices has brought about a whole palette of new possibilities and chances for geo information science and cartography". Mobile information retrieval has developed in parallel with geographic information retrieval, and there is considerable overlap between the two. The key distinctions between them relate primarily to the context of the use. The situations in which display devices are used are inherently associated with the physical environment, and a user's temporal constraints and activities, all of which influence his/her needs of information.

## 2.7. Context Of Use

As Gartner and Hiller (2009) asserted, it is essential that a balanced combination of scale, perceivable geo-information and selected content is aimed at when attempting to represent the spatial data for a particular purpose. This balanced combination has to be applied on map displays in relation to the context of use. According to Reichenbacher (2004), 'context' on a broad level is comprised of: situation, user, activity (i.e. task), information and system. Figure.2-1 summarizes the factors included in the basic components of context.

| Situation | User | Activity | Information | System |
|---|---|---|---|---|
| location<br>time | abilities<br>knowledge<br>preferences | locating<br>navigating<br>searching<br>identifying<br>checking | environ-<br>mental<br>features | hardware<br>infrastructure |

**Figure 2-1: Context Components (Reichenbacher, 2004, cited in Dillemuth, 2005)**

Context of use should be highly considered as it applies to both the physical location of the user in any given environment and to the nature of the interaction the user has through the display of the device, i.e. what does the space indicate about how a display could or would be used? For example, a very different usage scenario would be expected for a large, wall sized display in a communal area with no chairs than for a small, table-mounted display in a private office (Shupp et al., 2009). Different components of context may be important to different people at different times. The usage situation is composed of the physical, social and cultural environment (e.g. workplace, temperature, work practices, organizational structure etc.). Furthermore, user characteristics and usability components (like accessibility and portability) are strongly related to the context of use.

Various contextual elements (e.g., location, device, and task) have been considered of a high importance in order for the user to get what is most suitable for his/her needs. The combination of location and situation creates different contexts of use. Most devices are designed for specific contexts of use, which can be more or less dependent on either location or situation (Öquist et al., 2005). For example, a desktop computer is designed to be used primarily in a stationary location, whereas a mobile phone is designed to be used mainly in situations where one is one the move. By identifying the contexts of use, it is possible to identify which devices are useful in the situations and locations where a geo-application (i.e. map) has to be used. As described by Öquist et al. (2005), stationary context of use, which can be exemplified by the desktop computer, offers the versatility as a relatively large screen, a full-size keyboard and a full graphical user interface. In a mobile context of use, the device should be almost palm-sized and portable enough in order for the user to be able to move while holding it (e.g., smartphone or PDA) with one hand and operate it with the other, or operate it with the same hand that holds the device while having the other hand free to do other things. Furthermore, current activity and task are frequently cited as important components of context that have a direct influence upon information needs: an individual could be working, shopping, or driving, while attempting to solve specific spatial problems.

For solving a spatial problem, one is dependent on the availability of information about "where", which includes his/her own location as well as the locations of other relevant objects (target, decision points), as Downs and Stea (2005) stated. They argued further that besides information about "where", information about "what" is essential as well. Maps provide answers to concrete and simple geographical questions like: "Where is that street?", "How do I get to the railway station?", "Where do most people live in this country and why?" etc. Geographical problems are a little bit more complex when users are exploring a geographic dataset that is still largely unknown to them in order to gain understanding of and get insight into that dataset. Researchers have identified distinct categories of geospatial information needs (Gluck, 1996; cited in smith, 2012), and have developed typologies of geospatial tasks (Muehrcke, 1986, cited in Smith, 2011). Each of these unique dimensions has been found to shape the users' experiences with spatial information seeking tasks in general.

## 2.8. Spatial Tasks

Spatial information needs and tasks are of several kinds. There have been a number of simple classifications proposed as well as more detailed schemes. One simple approach states that geospatial information involves only finding responses to two questions: "What is there?" and "Where is that?". These include finding what is present at a particular location and all locations of a particular phenomenon. (Muehrcke, 1986, cited in Gluck, 2007) suggested another approach to the categorization of geospatial information tasks by describing three levels of sophistication of geospatial queries: reading, analysis, and interpretation. Reading involves extracting facts from a map such as the distance between two points, the name of a place, or latitude and longitude of a place. Questions about reading generally answer "what" questions or have "yes or no" responses. Analysis involves looking for relationships or seeing patterns in maps, such as noting that people living near polluted water supplies have high incidents of intestinal bacterial infections, or establishing a pattern for fossils distributed among rock layers. Analysis questions generally answer most "how" and relationship questions. Interpretation questions seek cause and effect such as all these trees were damaged because of the explosion of a nearby volcano. Such interpretation questions answer "why?" and some "how?" questions.

As stated by Lobben (2004), a spatial task may be completed by different map users through the use of different strategies. Map Reading Strategies are specific methods employed by a map user to complete a set of map-reading tasks. She identified a difference between strategies and processes is that everyone uses the same processes, but at varying levels of ability or effectiveness. However, the difference in an individual's ability levels in varying processes may decide the strategies they use. Thus, everyone may use the same processes, but not everyone uses the same strategies.

In 2D workspaces, a main distinguishing factor in categorizing spatial tasks is the spatial relationship between objects and the space. From this perspective, and according to Irani et al. (2007), tasks can either be *a) spatially absolute*, involving interpreting the relationship between an object and the underlying workspace; or tasks can *b) spatially relative*, involving identifying relationships between objects in a workspace. However, the list of tasks in each group is extensive and many other spatial tasks are performed on graphical workspaces. Irani et al. (2007) described each group as follows:

### a) Spatially Absolute Tasks

Spatially absolute tasks involve determining the relationship of an object to the workspace that contains the item. Some examples of spatially absolute tasks include determining whether an item is in the workspace at all, the number of occurrences of a certain type of item, or the location of an object in the workspace. Main types of spatially absolute tasks include: Existence, Object Count and Location

- **Existence**

A common question when browsing a graphical workspace is to ask whether a specific type of object exists. For instance, a user may want to determine whether a zoo, a museum or a library exists on a map. In such tasks, the user scans the entire workspace until the desired object is found.

- **Object Count**

Another common task is to determine the number of objects of a specific type. For example, counting the number of hotels or cinemas in a given area of the city may be necessary if the user wishes to compare hotels locations or to decide where to see a movie. In counting tasks, the user scans the entire workspace and mentally maintains a record of the objects found.

- **Location**

Location tasks necessitate determining the position of an object in the workspace. Sometimes a user would like to know only the quadrant of the city in which an object appears, and sometimes a more detailed location is needed. In this task, the user scans the workspace until the object is found, and then establishes the location of it with respect to the entire workspace.

### *b) Spatially Relative Tasks*

These tasks require the user to determine and understand spatial relationships between objects in the workspace. Main types of spatially relative tasks include determining the proximity of an object to a point of reference, the proximity of objects to one another, or identification of clusters of objects that match certain criteria.

- **Proximity to Point of Reference**

A user often needs to locate an object that is closest to a point of reference such as finding the metro station or gas station that is closest to the user's current position. These tasks are carried out by first locating the point of reference, and then by searching outwards to locate candidate objects. For each candidate that is located, the user needs to remember the current best candidate; when all likely candidates are checked, the user can determine which was closest to the reference.

- **Proximity between Pairs of Objects**

A number of tasks involve finding a pair of items that are close together but location in the workspace is not important, such as locating hotels that are close to a railway station. To complete this task, the user must locate all pairs of items in the workspace, perform distance comparisons to determine which candidate pair are closest together (or below some 'close enough' threshold), and remember the best pair.

- **Clusters**

Cluster tasks are a more complex variation of the proximity between objects. These tasks demand locating an object in the surrounding area (neighbourhood) of other objects. For example, a user may wish to locate a hotel that is near a supermarket, a bus route and a Chinese restaurant. In this task, the user has to perform a visual query over the entire workspace to locate the required cluster of objects.

In another classification of spatial tasks, Shneiderman (1996) in his well-known Visual Information Seeking Mantra: "Overview first, zoom and filter, then details-on-demand" defined seven basic spatial information seeking tasks as follows:

**Overview:** Gain an overview of the entire collection.
**Details-on-demand:** Used to 'drill' into a small subset of objects to show their attributes. Upon selecting an item or group to get the needed details, a usual approach is to simply click on the item to get a pop-up window with values of each of the attributes. The details-on-demand window can contain links to further information.
**Zoom in on items of interest**: Users typically have an interest in some portion of a collection, and they need tools to enable them to control the zoom focus and the zoom factor. Zooming helps users preserve their sense of position and context.
**Filter out uninteresting items:** By allowing users to control the contents of the display, users can quickly focus on their interests by eliminating unwanted items.
**Relate:** View relationships among items.
**History:** Keep a history of actions to support undo and replay.
**Extract:** Allow extraction of sub-collections and of query parameters.

During the exploration of a specific space, the user is confronted with different information seeking tasks to be solved using a map. Giving the fact that map content (for the selected map extent) is often too voluminous to be visualized with the desired degree of detail on a single screen, and following his visual information seeking mantra: "a general vision first, after that a closer approach and a filter, and finally details about the part of interest", Shneiderman (1992) created four stages in the process of information search using a map, and to each of these he has added a visual component:

**1)** First, the user has to get a grasp of what can be found on the map and where it is located, i.e. the user sees the overall information he can find, what subjects are contained within the overview (which is the big picture that provides context).
**2)** Once viewed in a general way, the user zooms in so he centres on one part that is of major interest.
**3)** In order to refine his search better, he applies a filter, so that the results obtained better match his information needs.
**4)** To end the process, the user asks for more details from some of the results in order to determine if they are of interest or not.

According to Ball (2006), the user has to first select an area of focus before indicating (via suitable interaction with the interface) that further details are requested. That is because when people can see a greater context, they would be able to understand the "big picture" better. Understanding how the small pieces form the whole would help people have a better plan to execute their tasks.

The majority of spatial tasks seem to be represented by three main areas of web map purpose: Navigation and getting directions, Show points of interest (POI), and Show relationships and compare items geographically (*URL 13*). Typical tasks when viewing a web map are locating a certain place or a land mark, tracing a route from source location to a destination location and judging distances. A user might need to find relevant locations (e.g. the nearest metro station), compare alternative locations (such as a selection of restaurants where the user can see how far away a restaurant is from his current location and whether it lies close to other locations that he considers visiting). Since it is not possible to cover all types of spatial tasks earlier discussed in this section, the spatial tasks for the experiment in this research are mainly formed to cover a range of common practical tasks with relation to Shneiderman's mantra: "overview first, then details on demand", to investigate when an overview would be useful, when seeking details is required, and how all that could relate to screen size.

## 2.9. Conclusion

As a theoretical foundation and necessary steps towards fulfilling the main objective of this research, in this chapter: spatial tasks were categorized, contexts of use were described, display characteristics were outlined, spatial information was define and Interaction techniques were clarified, all besides reviewing some previous studies that relate to the main topic of this research. Next chapter elaborates on the methodological approaches employed in this work.

# 3. RESEARCH METHODOLOGY

## 3.1. Introduction

This chapter identifies the methodology that was applied in this study. It exhibits an overview about the approaches selected to obtain answers to the research questions posed in chapter 1, along with argumentations for and justification of these approaches.

## 3.2. Data Collection

Nielsen (1993) discussed several methods for collecting usability data and these include: think aloud, questionnaires, logging actual use, observation, and user feedback. In addition, Dix et al. (2003) pointed out several approaches of collecting context of use information, among them are: surveys, interviews, eye-movement tracking and observations of users in field studies. For researches that are exploratory in their nature (like this research), a combination of qualitative and quantitative research techniques centred round the think aloud method leading to verbal and action protocols to be analysed appears to be most promising(van Elzakker, 2004). In this research, collecting data will be achieved through the following methods:

- ***Think aloud:***

  Refers to a method of inquiry where users explain aloud what they think as they carry out a task or assignment (Khan, 2010). It is a form of observation where the user is asked to describe his / her actions verbally and talk through what he/she is doing or what kind of problem appears while performing the test. Besides simplicity, this method has the advantage of providing much qualitative feedback that otherwise would have been uncovered (Beer et al. 1997). It offers a rich source of attaining data, and it gives a detailed insight of the usability problems as perceived by the users themselves (Jaspers, 2009). However, a disadvantage of this method is that analysis of the data is usually time consuming.

- ***Screen logging and video recording:***

  In order to be able to properly analyse user activities, things that are happening on the monitor screen have to be recorded. Screen logging and video recording are methods of observation where data is collected automatically while the users are performing the test. Through screen logging, all the activities on the screen are recorded and can be replayed at a later stage. The main disadvantage of screen logging is that, although it shows what the users are doing, one cannot know why the users were doing what they did (Nielsen, 1993). The think aloud technique was selected in this research as a solution to this problem. The recording of the voice while the test person is performing tasks helps in supplementing the data collected with screen logging. A limitation of the thinking aloud technique is that some users cannot think aloud constantly during the test session and eventually they may keep quiet. Video recording was used in this study to capture test persons' expressions for both who could and could not think aloud well in order to reveal exactly how they were behaving during the test. Video recording supplies relevant body language information along with the words spoken out loud. A benefit of this technique is that testing sessions can be reviewed over and over again in a detailed way (Jaspers, 2009). The combination of spoken and body language gives a much better indication of the actual thinking process than spoken language alone (van Elzakker, 2004).

● ***Questionnaires:***

Frequently used in use, user and usability research since they are relatively easy and inexpensive to compile and evaluate the relevant information related to the user and context of use. Examples of the styles of questions that can be included are: open-end, multiple choice (closed-end) and ranking questions. Questionnaires with close-ended questions are mostly used in usability experiments because their analysis is time-saving and they are easy to be interpreted (Barnum, 2002). In this study, three questionnaires were designed (with a mixture of both open-ended and closed questions) to be filled out by each test person, those are:

i) *Pre-Test Questionnaire*: to be completed at the beginning of the experiment. It was designed to collect self-report data containing questions on general background and demographic characteristics (including age, gender, field of study), experience in using maps, prior use of mobile devices (tablets and smartphones), familiarity with touch screens, knowledge of the test area, etc.

ii) *Post-Test Questionnaire*: to be completed upon conclusion of the experiment. It was designed with questions adapted from the Mobile Phone Usability Questionnaire MPUQ (Ryu, 2005) to compare the overall experiences TPs obtained from using the 3 display devices to read maps. This questionnaire demonstrates TPs opinions and preferences, and identifies their behaviours (strategies) which could be linked to the quantitative data gained from the log files (recordings). Information from this questionnaire provides a better insight into subjective evaluation and satisfaction which may not be so explicitly measurable during the actual test on the displays.

iii) *Nasa TLX- Task Load Index:* is a subjective workload assessment tool that allows users to perform subjective workload assessments on operator(s) working with various human-machine systems (*URL 14*). NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales. These subscales include: Mental Demands, Physical Demands, Temporal Demands, Performance, Effort and Frustration. NASA-TLX can be used to assess workload in various supervisory and process control environments, simulations and laboratory tests. After each display device was tested, a modified version of NASA TLX (Hart and Staveland, 1988) was administered on paper. This questionnaire consisted of several questions with 4-points response scale (Not At All, Slightly, Moderately, Very), it was used to attain information about the test person's perceived task load on each of the three tested devices.

● ***Interviews:***

Provide a direct and structured way of gathering information. They should be planned in advance with a basic set of questions, and may then be adapted to a specific user and be varied to suit the situation. Typically, questionnaires and user surveys are planned beforehand as well but they are less flexible than interviews. However, they take less time to administer, and can be used to reach a wider group (Fendel, 2007). In this study, the TP was debriefed as a final stage of the experiment after having the post-test questionnaire completed. TPs' responses and comments were noted down and used as a supplement to the data collected with think aloud and video recording.

● ***Eye tracking:***

Refers to the collection and analysis of the human eyes' movement. It gives real-time feedback of that movement while the TP is carrying out the test, showing where he/she successively looks at and for how long (*URL 15*). As described in Ooms (2012), this technique allows 'tracking' the movements of the user's eyes: his Point of Regard (POR) is registered at a certain sampling rate. From this long list of (x, y) positions, eye movement metrics such as fixations and saccades can be derived. A fixation is a stable POR during a certain time span (at least 80 to 100 ms) and indicates that the user is interpreting the content at that location. More recent studies show that eye movements are critical to interpret visual information efficiently while performing a complex visual and cognitive task (Duchowski, 2007, cited in Ooms, 2012). The software packages that come with these eye trackers today allow more flexible extractions of meaningful metrics related to fixations and saccades (Duchowski, 2007; Poole & Ball, 2006, cited in Ooms, 2012). Not only what a user is looking at but also how long, how often, the length and speed of the saccades, etc. can be discovered. As a consequence, more detailed insight in the user's cognitive processes can be derived from these measurements (Ooms, 2012). This methodology technique was mainly selected in this research because it helps to know how the human eyes move and where they look at on the different-sized screens while people are trying to get an overview and/or details of the maps displayed on those screens.

### 3.3. The Applications Used In This Experiment

■ ***Google Maps®:***

The well-known and widely used application Google Maps® has the capacity to satisfy the diverse "where", "what" and "when" aspects of queries (Khan, 2010). It represents a comprehensive yet simple way for an online mapping solution. Google Maps® helps people search for specific locations and get directions to those locations, along with providing detailed information and photos about them, in addition to many innovations in the user interface, like viewing traffic information, viewing maps as satellite imagery, printing the desired maps and sharing the maps with other people (Hernandez, 2009, cited in Khan, 2010). As shown in Figure 3-1(a), the central part of the page is covered by a map that users can zoom in on or zoom out and pan through virtual navigation controls (positioned on the left side of the map). On the desktop display, the users can interact with the map by using controls (like the arrows and the zoom slider), or by the mouse's clicks and scroll wheel. While on the tablet and the smartphone, besides having controls (as shown in Figure 3-1(b)), the users can manipulate the map by using their figures to tap and pinch on the touch screens. Moreover, the users can find their desired location by entering a text address in the search box at the upper left corner of the window. Getting directions is a feature through which users can get directions from one place to another. The getting directions function has different options, for different forms of mobility such as through public transit, by walking and by car.

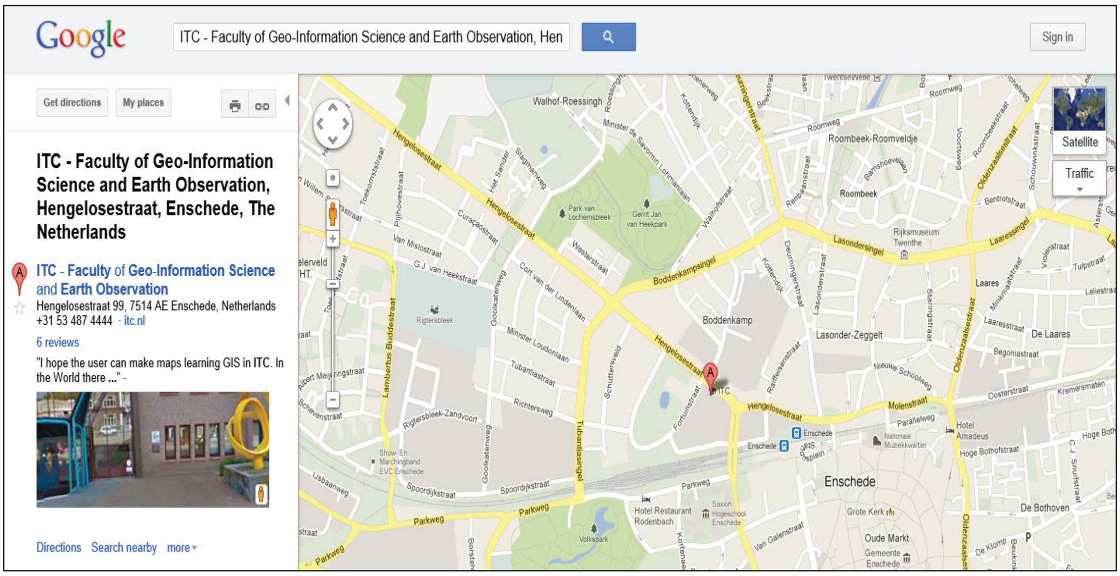



**Figure 3-1(a): Google Maps® desktop Interface**

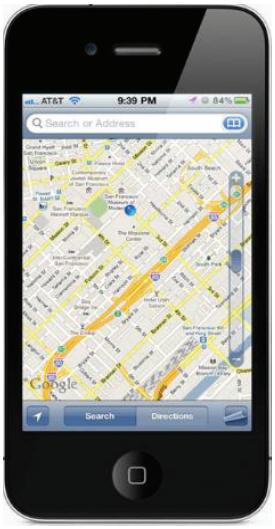



**Figure 3-1(b): Google Maps® smartphone Interface**

■ ***The Weather Channel Application®:***

Maps are also important means of information dissemination for websites like The Weather Channel® (*URL 16*). This online service has feature that show the weather forecast by means of animated maps that display the movement of the clouds for various parts of the world. These animations are based on time sequences. Figure 3-2 illustrates The Weather Channel application's interfaces on the desktop and on the smartphone. See Appendix (A) for a quick guideline on how to use this application.

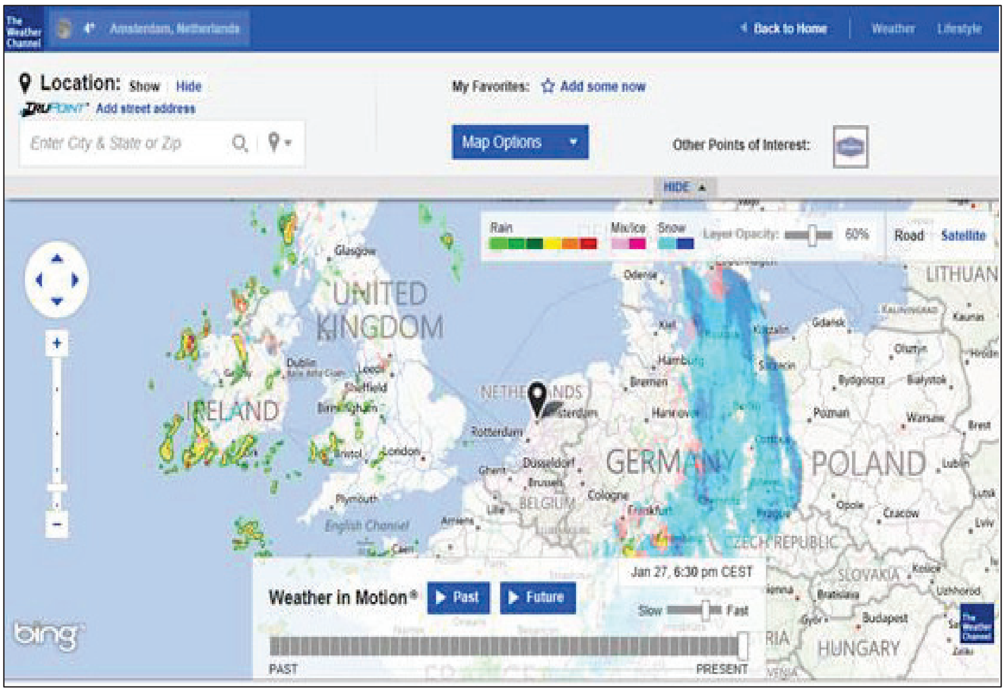



**Figure 3-2(a): The Weather Channel® desktop interface**

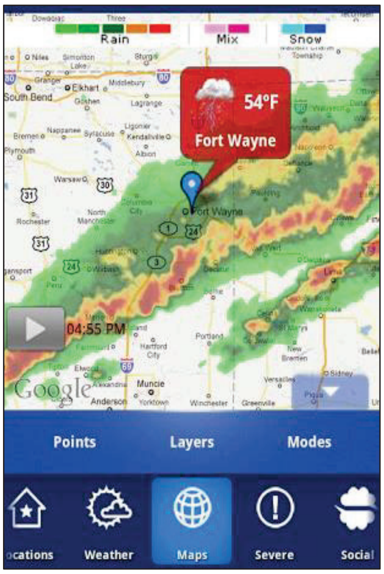



**Figure 3-2(b): The Weather Channel® smartphone interface**

Google Maps® and The Weather Channel® applications were mainly selected in this experiment (as a test environment) because they offer interactive 2D maps that are able to be manipulated. Furthermore, and besides the classic desktop interface, those two map-based web services have interface designs that are especially developed for the smartphones and the tablets.

### 3.4. The Tasks Performed In This Experiment

In order to undertake an empirical comparison study in performing spatial information seeking tasks across three varying screen size devices (large: desktop, medium: tablet, small: smartphone), three similar blocks (sets) of spatial tasks were formulated. The tasks were meant to be executed in a controlled lab experiment. They provide a representative sample of real and common types of spatial tasks that a typical user might frequently execute using a display device. Those tasks were designed to help finding answers to questions posed in this research relating to identifying what interactions the users apply in executing those spatial tasks, along with discovering - in a qualitative sense - what goes on in the users' minds when they are interacting with different screen sizes to get an overview and/or details on demand.

Knowing that only a limited amount of time and resources are available to conduct a user testing in this work, it has been decided that it would be most productive to focus on common geographic tasks (e.g. route planning). Tasks in this experiment were designed based on possible scenarios one could potentially encounter in real life. The TPs were asked to picture themselves in a situation in which they would be using one of three devices to plan a route between two cities and check the expected weather conditions during the planned trip. Basing tasks on a real life situation makes them relevant, while also encouraging the TPs to behave in a natural way to imitate their actual experiences in performing those tasks on different display devices in real situations. In the scenario where 'a person is planning a route between two cities', few examples of actions that he/she might be involved in are getting a grasp of where the destination city is located and what can be found about it using the map, having an overview of the planned route and of the points of interest (POI's) in that city, and then go deeper into the level of details to find specific information about specific POI's.

Explicitly, the operational tasks performed across the three computing platforms in this experiment involved: *Route Planning, Searching* (find specific locations and show points of interests), and *Visual Comparison* (illustrating the relationships and trends geographically). To establish a link between such tasks and the spatial tasks description mentioned earlier in chapter 2 as derived from theory (specifically from Shneiderman's mantra: overview first, then detail on demand): route planning demands having an overview of the whole route with its both ends seen on the screen while searching for targets on the map involves looking for details as it calls for navigating to potential areas of interest, deciding if the search conditions were met, then stopping as the task is finished or repeating the process of navigating and deciding until the search requirements are fulfilled. Moreover, the comparison task necessitates looking for overview and details as it requires navigating to search for objects (points of interest) on the map that meet the same search criteria, and then comparing them.

### 3.5. Arrangements Made To Carry Out This Experiment

The best approach to carry out this experiment is to let every TP test the three devices successively. That was not possible planning-wise due to the changes required in the hardware set-up in the lab. Since the devices cannot be tested immediately after each other, this experiment was divided into three sessions and each TP was asked to come to the usability Lab three times in consecutive days (based on pre-scheduled appointments). During those /3/ sessions for each TP, he/she was asked to perform a block of spatial tasks on one of the three devices in the following order: desktop computer session, then smart phone session, and tablet session at last.

Hypothetically, it was assumed that the desktop would be probably the easiest display device to work with. If a TP started the sessions with using smartphone, he/she would possibly face difficulties to come at grips of the tasks, along with difficulties of operating the interfaces of the testing environment (Google maps and The Weather Channel). Hence, by starting with the smartphone and ending with desktop, everyone will feel that the desktop is the best display, because when they would be testing it at the end, they would already knew the tasks and the applications; that learning effect could bias the test result. Thus, in order to keep the learning effect at its minimum, it has been decided that the desktop is the most fair to start with because usually people are most familiar with using it, so they would be spending time on focusing on the tasks and the characteristics of the applications. Now after they got familiar-to some extent- with the tasks and the applications (Google maps and the Weather Channel), the TPs may test the other two devices where their main focus would be on the device characteristics (e.g. touch technology, screen size) since the tasks and the applications are already known to them by then.

### 3.6. Conclusion

Research objectives, time cost, and availability are some matters that influence the choice of the methods to be applied. Further description of the methodology approach used in this research project was clarified in this chapter. Several different quantitative and qualitative methods were used in combination to complement each other in collecting data and provide additional information. Those methods were: thinking aloud (audio recording), video recording, screen logging, interviews and eye-tracking. In addition, paper-based questionnaires were used to gather data on the TP's characteristic, satisfaction, preference and workload. These questionnaires helped describe a more complete and rich picture than the empirical data alone would permit. In the next chapter, a broad description of the experiment's design, setup and procedure is pointed out in detail.

# 4. THE EMPIRICAL WORK

## 4.1. Introduction

In this study, the use of maps through two web applications (Google Maps® and The Weather Channel application) across three display devices (smartphone, tablet, desktop) was evaluated to find out to what extent screen size affects spatial task performance. For this aim, a laboratory experiment was conducted where questionnaires were distributed and interviews were held. Students from ITC were invited (by e-mails) to participate in this experiment. Ten test persons (TPs; seven males and three females) were selected. The specific appointments for each TP's sessions were defined according to his/her availability (a calendar was previously defined). This chapter discusses the empirical work of this study. It illustrates specifications of the apparatus used in the experiment, and the pre-defined tasks the TPs were asked to perform. In addition, the test-set up and procedure are described thoroughly.

## 4.2. The Experiment's Apparatus

### 4.2.1. Display Devices

This experiment is about having TPs completing spatial tasks through map displays on three devices with different screen sizes: small size=smartphone, medium size=tablet and large size=desktop computer. Table 4-1 shows the display specifications for the display devices used in this experiment.

| *Device* / *Feature* | **LG W2242PE**  | **iPad-1**  | **iPhone 3gs**  |
|---|---|---|---|
| **Monitor Size** | 22- inches Widescreen LCD Monitor aspect ratio 16:10 | 9.7-inches (diagonal) widescreen multi-touch display | 3.5 inches (diagonal) widescreen multi-touch display |
| **Resolution and pixel density** | 1680 x 1050 | 1024 x 768 at 132 pixels per inch (ppi) | 320 x 480 at 165 pixels per inch (ppi) |
| **Operating System** | Microsoft Windows7 with Internet Explorer | Apple's iOS | Apple's iOS |

**Table 4-1: Display Device Specifications as used in the experiment**
(Sources: *URL 17, URL 18, URL 19*)

#### 4.2.2. Equipment Used

In addition to record human eye movements, the eye-tracking system used in this experiment facilitated screen logging, making video recordings of the TP and sound recordings of their thinking aloud. The hard- and software needed for this is incorporated into the Tobii system as follows:

***a) Hardware***

- *Tobii X60 stand-alone eye tracker:* This eye tracker can handle natural head movements, providing a test environment that ensures natural behavior. Robust eye tracking capability ensures accurate results and very low data loss, regardless of a user's use of glasses, contact lenses or mascara (*URL 20*). As Figure 4-1 shows, the desktop screen was fixed to a tabletop surface while the Tobii X60 eye tracker was mounted below this screen.

**Figure 4-1: The eye tracking system in the desktop setting**

- *The Tobii Mobile Device Stand*: a full HD scene camera (maximum resolution 1920 x 1080 pixel), which also records sound via a microphone, included with an adjustable mounting arm (see Figure 4-2). It is designed to test mobile devices using the Tobii X60 eye tracker, allowing the user to interact with the mobile device in a natural way with the possibility to freely rotate between portrait and landscape modes. This stand helps deliver high precision eye tracking data needed to test small devices like mobile phones; and it also enables eye tracking of larger (up to 10" size) devices like e-readers, tablet (*URL 21*).

As can be seen in Figure 4-2, the camera was mounted using flexible arms to capture streaming video of the downward view onto the mobile devices. Moreover, the armed camera, the mobile device and the eye-tracker are all positioned on a small table that can be moved up and down to adjust the height of the whole gear according to the TP's length. For each TP, his/her length was taken as shown in Figure 4-3. Also, the chair a TP used to sit on while testing the devices is fixed (i.e. wheels free) to ensure the least body and head movement of the TP while the eye tracker is working.


**Figure 4-2: The eye tracking system in the mobile device setting**
*(At: the ITC usability lab)*

**Figure 4-3: Measuring the TP's Length**
*(Picture taken by Mr. Willy Kock)*

***b) Software***

*Tobii Studio® eye tracking software (version 3.2.0):* provides a comprehensive platform for test design, recording, observation, visualization and eye tracking data analysis. Tobii software has several analytical features and visualization tools that usual video recording software doesn't have, like generating heat maps, gaze plots, along with providing statistics in table format and graphs. Furthermore, it gives the ability to analyse segments separately with support of the replay functions, event logging, scene tools and filters (*URL 22*).

### 4.3. The Experiment's Tasks

A real world scenario was employed to cover a range of spatial tasks implemented to answer different kinds of geographic questions. Such spatial tasks were selected because they are common visual analytic tasks that require the user to utilize the display in different ways while navigating a map-based web environment.

Principally, in this experiment, TPs had to do tasks typical for the use of a map: route planning and checking the weather forecast, along with other tasks like find locations and compare objects on the map. Route planning and locate places require the TP to traverse a specific portion of the data without losing context. On the other hand, comparing objects requires the TP to develop methods to visit the entire set of data in some efficient manner, do the comparison and then make decisions. The three similar task blocks each TP completed are illustrated in Appendix (B). Each block has 6 tasks included (Task 1, Task 2,.., Task 6). Table 4-2 shows a short description for each task.

| Task no. | Description |
|---|---|
| 1, 4 | Route planning<br>(requires overview) |
| 2 | Search and find a location<br>(requires overview, and 'some' details) |
| 3, 5 | Find objects' locations and compare between them on the map<br>(requires overview and 'deep' details) |
| 6 | Find locations and play the animation<br>(requires overview) |

**Table 4-2: Tasks' description**

### 4.4. The Experiment's variables

Variables in this experiment come in two main types, those controlled (independent) and those measured (dependent). The following explains more about each type.

- ***Independent (controlled) variables*** include: physical diagonal display size (in inches) (which is the actual amount of screen space that is available to display information).

- ***Dependent (measured) variables*** include:

  - **Interaction activities** this work seeks out to know how users go about when trying to get overview, then detail while solving spatial tasks. For that purpose, the type and amount of interactions with the displays were logged to be able to measure the number of zoom actions (zoom in and zoom out) and pan actions (dragging the field-of-view on the screen).

  - **Work load** task load (i.e. subjective mental effort) associated with each display tested, along with evaluating individual satisfaction and preference.

  - **Task-completion time (in seconds)** though it is not an essential matter this study attempts to explore, it would be good to make note of it. The overall task completion time was defined as the total time spent on working on the tasks. Timing starts when the TP states that he/she is ready to begin solving the selected task block after reading it, timing was concluded when all tasks objectives were completed successfully.

In another classification, this experiment has two types of measures to be assessed:

- ***Quantitative measures*** including the task completion time (total time spent working on tasks), the amount of interaction to execute the tasks. Data about such measures was obtained from the screen logging and video recordings incorporated in the eye-tracking system.

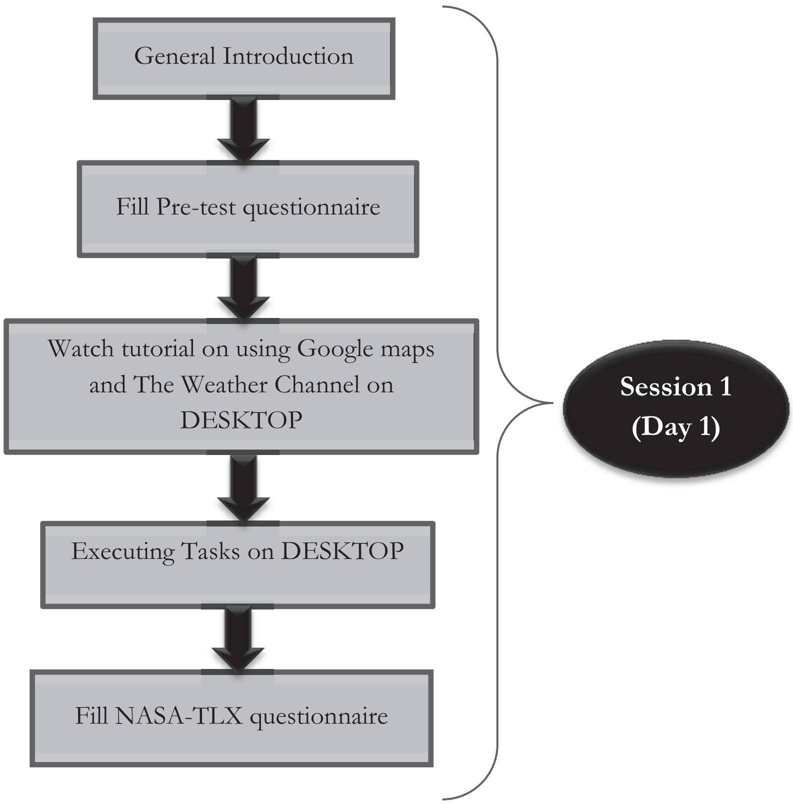
- ***Qualitative measures*** including the TPs perceived task load associated with using maps on each display device, and subjective (individual) impressions and preference. To support subsequent data analysis, information about such measures was acquired via NASA Task Load Index questionnaires, post-test questionnaire, the structured interviews, and the thinking aloud observations.

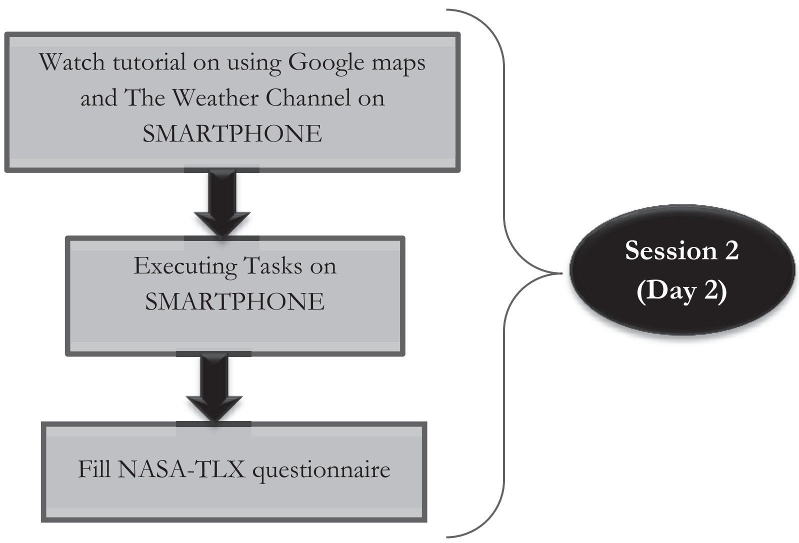
Students from ITC were invited (by e-mail) to participate in the experiment. Ten test persons (TPs; seven males and three females) were selected. The specific day and hour in which each TP carried out the experiment was defined according to his/her availability (a calendar was previously defined).

### 4.5. The Experiment's Procedure

This experiment was organized to determine the impact of the display size on spatial task performance. Before starting the actual experiment, pilot testing with volunteer was done to ensure fine tuning of the test-set up, and refine the designed tasks so that the TPs in actual testing would not face problems. Yet, the pilot testing results were not included in the results analysis in chapter 5. Also, all the necessary equipment for the experiment was checked before the testing to avoid any technical problems while performing the tasks. This experiment was conducted in the usability laboratory in ITC where the TPs' uses of the three specified devices (desktop, tablet, smartphone) were recorded. Three similar blocks of tasks were formed for map reading. In total, 30 sessions were held in the lab, since the experiment for each TP was divided into 3 sessions. Each session lasted about 40 minutes.

Because Every TP has to do the test with every device, and in order to prevent a learning effect bias, different destinations and places to be visited were involved among the three task blocks to ensure that each TP has a different context on each device to be tested. The TPs selected the block of tasks to be executed on each device randomly. For instance, in the first session (desktop session), a TP picked one of the 3 blocks randomly. In the second session (smartphone session), that TP picked a block from the 2 remaining blocks. In the last session (tablet), that same TP picked the only block left (i.e. the one that was not executed on the previous two sessions). Appendix (C) shows the distribution of the task blocks among the devices for each TP. So, in order to keep an administration of the test set-up, the distribution of the three task blocks for each TP was randomised whereas the order of the devices to be tested was not (each TP tested the desktop first, then the smartphone, then the tablet) as previously explained in chapter 3.



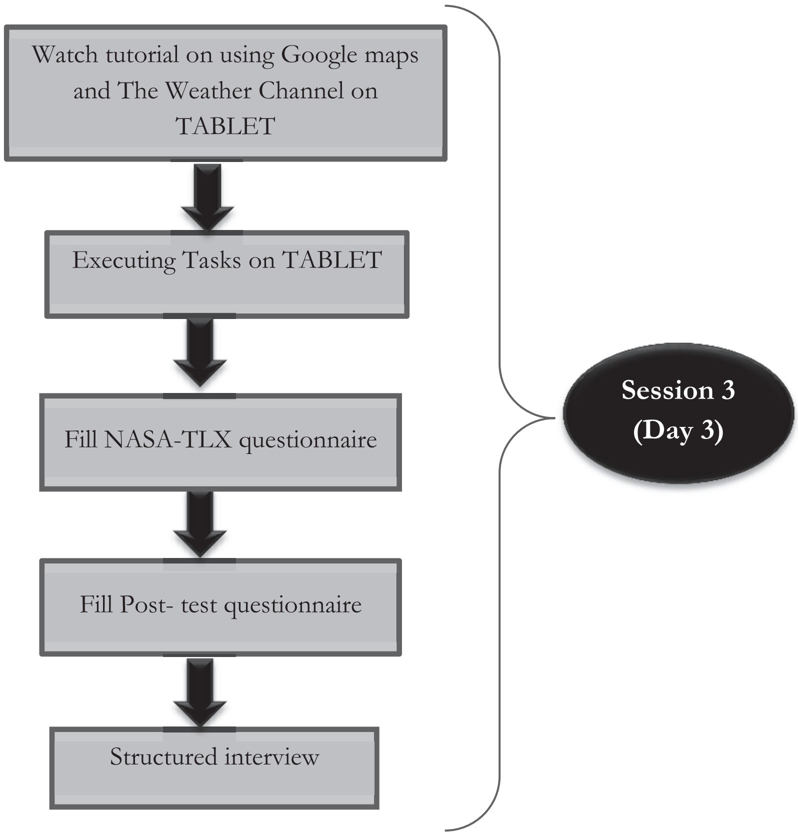



**Figure 4-4: Flowchart of the experiment's procedure**

Figure 4-4 clarifies the experiment's procedure. Before the Start, each TP read about the underlying rationale behind the experiment in a short introduction (Appendix (D)), and then a brief description of the testing procedure was given (Appendix (E)). For each TP, sessions started with the TPs answering a pre-test questionnaire (Appendix (F)) focusing mainly on demographic data, experience with the touch screens, with reading maps and with 2 applications (Google maps and The Weather Channel). On completion of this questionnaire, a short introductory training was given (brief tutorial movies) demonstrating how to use Google Maps and the weather application on the device to be tested in the session (i.e. desktop in session one, then smartphone and tablet successively). By doing so, the TP was given the opportunity to familiarise him/herself with the displays and with the interfaces of the applications involved.

Afterwards, the TP's eyes were calibrated. The calibration on desktop was automatic whereas it was manual for the tablet and the smartphone. Once the TP felt comfortable and ready to proceed, he/she selected a task block (printed instructions sheet) to obtain a clear description for each task (Appendix (B)). The TPs were observed while completing the tasks independently, they were encouraged to 'think aloud' and describe the rationale behind their actions. They were asked to speak aloud their thoughts and intentions as they are interacting with the displays so that an accurate picture of their mental processes and how they perceived maps on each display could be obtained. Taken from actual data captured, Figure 4-5 shows screen shots of TPs performing tasks on the displays.

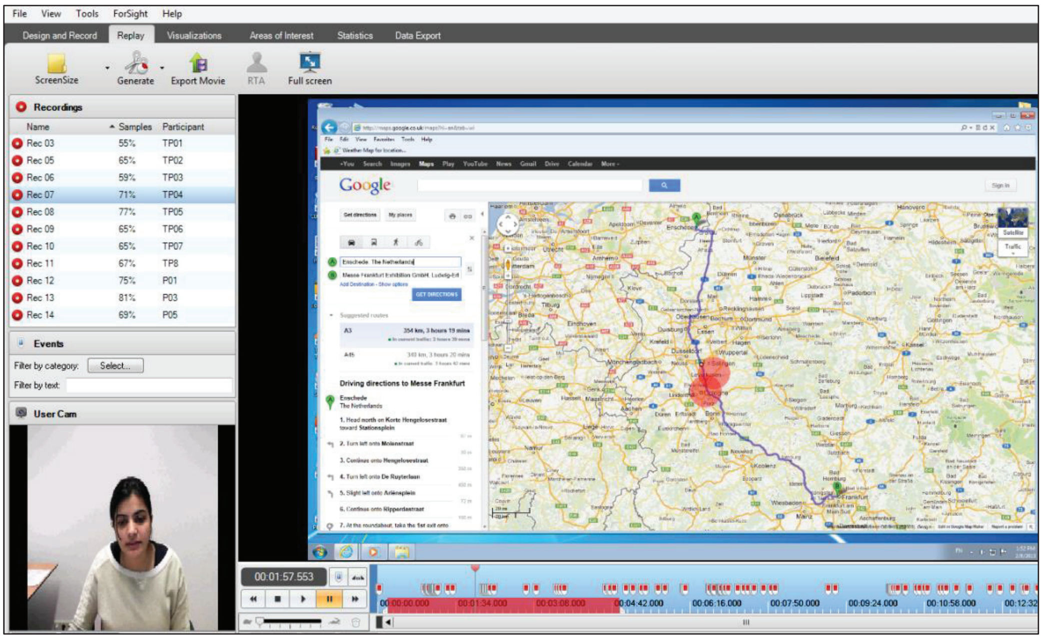



**Figure 4-5 (a): Screen shot of a TP performing on the desktop**


**Figure 4-5 (b): Screen shot of a TP performing on the smartphone**

Directly following successful completion of tasks execution, NASA TLX (Appendix (G)) was administered to obtain information on the subjective workload (i.e. mental effort). This procedure was repeated for all the three display devices, each in its allocated session. In the third session, and once the TP completed the tasks on all three devices, he/she was asked to complete a post-test questionnaire (Appendix(H)) which was designed to do comparison between the tested displays. Afterwards, a structured interview with open-ended questions (Appendix (I)) was conducted to gauge TP's satisfaction levels and overall experiences with the three tested displays, and to uncover any specific problems they encountered with a given configuration. Interviews with TPs yielded valuable information in understanding more about the benefits and drawbacks of using each device to read maps.

## 4.6. Limitations and Implementation Constraints

As this research is concerned with how maps presented on several displays are dealt with by different users, a number of implementation issues must be considered. For the purposes of control and simplicity, this experiment was narrowed to using 2D geographic web maps in the context of single-user scenario (no collaboration).

This research did not intent to study neither a particular visualization technique nor a representation, but to compare the user performances when using different sizes of displays to read maps. In an effort to make comparisons between these displays, many things must be considered, yet it is not always possible or practical to consider every aspect of a given computing device when comparing it to another. Based on that, issues related to the variation in screen resolution and pixel density among the three display devices are not addressed in this work. Also, it is beyond the scope of this research to discuss issues about the map cartography that relate to the graphic appearance and cartographic interface design; like size of the view window (port) on the screen and the map symbology.

Research in geography and psychology on individual differences and their relationship to spatial cognition indicate that variations in spatial abilities and gender-based preferences influence the performance of spatial tasks (Dillemuth, 2005). Next to the differences between the TPs in backgrounds and experiences, there are also differences in visual and spatial abilities, and evidently differences in gender. However, it is beyond the scope of this research project to establish such differences.

During the laboratory tests, the TP sat in a comfortable and natural position that is suitable to capture the movements of his/her eyes. However, variations in the distance from the screen for the three devices were not considered. Another aspect of the laboratory context that could be a limitation of the study: having the mobile display devices (i.e. tablet and smartphone) fixed to a surface. This did not only ensure that video data could be collected via overhead cameras, and the eye-tracker works properly according to the calibrated eyes of the TP. But it also maintained a similar interaction experience for all the TPs. However, it would not be the typical normal choice for most people to interact with fixed smartphones and tablets.

Moreover, another limitation to this work could be the fact that the actual user test (i.e. dealing with the display device) was only conducted in a controlled lab environment and not on the move out-doors. Thus, for mobile devices, it won't be possible to generalize this work's results to more everyday (realistic) operating conditions.

Besides the screen size, other aspects may influence task performance (e.g. the nature of the interfaces and the user familiarity with the applications).To minimize the influence of such aspects, the same applications were used across the different platforms; because the basic design and features of these applications would mostly be quite similar across the different display devices.

Last of all, this study only scratches the surface in terms of all the types of tasks being performed by the TPs in the experiment. It is a reasonable starting point focusing on simple classic spatial tasks that utilize maps across three display devices.

### 4.7. Conclusion

The contribution of this work is to explore the impact of screen size on spatial task performance. A special interest here is to see how people's behaviours differ for different sizes of displays. For this purpose, and to help capture and analyse user experiences across a range of display devices, a lab experiment was conducted in which TPs had to complete geographical tasks on a desktop, a smartphone and a tablet. Principally, the format of the experiment incorporated: a pre-test questionnaire, actual test, task load index questionnaire, post-test questionnaire and interview. The equipment used, the tasks executed and the experiment set-up were clarified in this chapter. Each TP was encouraged to say what he/she thinks, feels, and does while executing a block of spatial tasks using one device at a session (starting with desktop, then smartphone, and lastly tablet). To avoid (minimize) any possible learning or ordering effects, each task block was involving different places on different maps. In sum, each TP completed /five/ individual questionnaires and was debriefed in a structured interview. During the experiment, and by exploiting the eye-tracking system, different items were captured: thinking aloud together with images of the TP interacting with the map displays, eye movement of TP on the screen, the TP's behaviours and how much he/she interacted with the map. The results for the analysis of the quantitative and qualitative data collected (recordings, questionnaires and interviews) are presented in the next chapter.

# 5. RESULTS ANALYSIS

## 5.1. Introduction

A comparison of similar spatial tasks performed on a desktop, a tablet and a smartphone under similar testing conditions was undertaken involving ten TPs. Comprehensive analyses of all the results collected from the lab test, questionnaires and interviews are presented in this chapter. Comparison of map use experiences on the three display devices is discussed, along with the feedback from the TPs' interviews and observations related to their eyes movements.

In this chapter, the quantitative results analysed include:

- Descriptive statics about the amount of interaction activities (i.e. zoom in, zoom out, pan) for each device per TP, and per task.
- The total time to complete a set (block) of spatial tasks on each device.

Whereas the qualitative results analysed include:

- Task load measures of the TPs for each device tested, and a comparative assessment across all devices.
- Interviews' details and feedback to assess factors not addressed by the task load index or the post-test questionnaire.
- Analysis of the TPs' subjective evaluations and preferences (individual satisfaction)

## 5.2. Results from the Pre-Test Questionnaire

In order to characterize the TPs, descriptive statics for their data are illustrated in this section. The demographics about the TP's and their individual characteristics, along with their experience in the geo-domain and their knowledge of Google maps® and of The Weather Channel® application are presented in Appendix (J). Among the ten TPs involved, six of them are in the age range (25-30), three are in (31-40), and the youngest TP is in the age range (18-24). There was one PhD student, four MSc graduates, and five MSc students. All TPs had normal or corrected-normal vision (e.g. glasses) with no colour-blindness.

All TPs reported having previous map display experiences. However, the level of that experience differs across the devices they used to read maps on. When asked about the map display device most often used, all TPs replied with having used maps on desktop for daily or weekly basis, but none of them have used maps on neither tablet nor smartphone every day. See (Appendix (K)) for detailed individual information about the TPs experiences, as derived from the pre-test questionnaires.

While all TPs know about Google maps® and all of them reported having experience with using it for route planning, only four TPs know about The Weather Channel application®. In addition to collecting demographics, the pre-test questionnaire asked the TPs about their level of experience in using devices with touch screens (Figure 5-1), along with the frequency of their usage of maps on the three tested display devices, their previous experiences in using Google maps® and the animated maps in The Weather Channel application® (Figure 5-1).

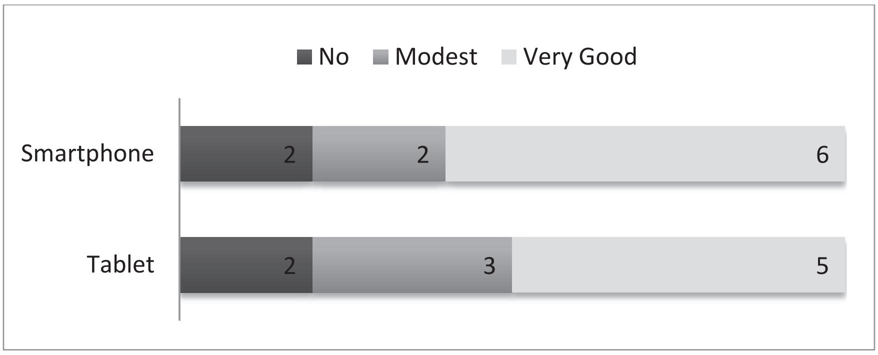



**Figure 5-1: TPs' experience with touch screens (tablet and smartphone)**

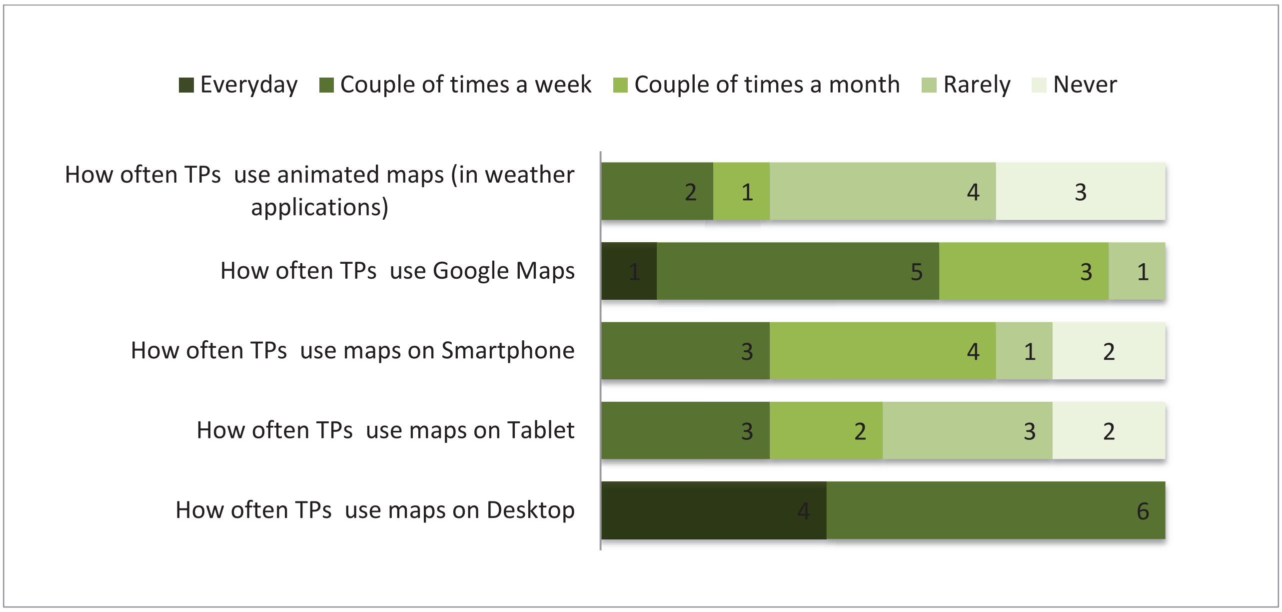



**Figure 5-2: TPs' experiences with applications and devices used in the experiment**

*(The numbers on the bars represent the count of TPs)*

By individuals, TP 2,3,5,6 have used Google maps® on the three devices before, while TP1 and TP7 have used Google maps® only on desktop computers. The remains TPs (TP4, 8, 9, 10) have used Google maps® on both desktops and smartphones, but not on tablet. With regards to the familiarity of the TPs with the areas in the test (cities of Hamburg, Berlin and Frankfurt), only two of the TPs have average familiarity with those three German cities, while the rest of them have no familiarity at all.

In order to know more about TPs preferences for the display devices, a question in the pre-test questionnaire asked them about which display device they would pick up to perform a set of common spatial tasks if they were in a room where a desktop, a tablet and a smartphone were available for them. Interestingly, the responses varied among TPs. TP1 and TP7, who reported having no experience with touch screen devices, chose desktop saying that it feels natural and easy to work with. TP2 and TP10 also made the same choice, saying that it is easier to deal with the desktop because of its big screen and input devices (e.g. mouse-keyboard). TP6 and TP9 also picked the desktop, because they think its screen is big enough to pan the map freely, it provides a bigger extent of the visualized map which consequently enables a better insight. TP4 and TP8 selected the smartphone saying that it is handheld and portable where one can carry it around all the time and easily have internet connection. TP5 and TP3 preferred using tablet because they believe this device is more user-friendly, comfortable and fun to deal with than the desktop. In total, six TPs went for the desktop, two for the tablet, and two for the smartphone.

## 5.3. Results from the Actual Lab Tests

In this section the results of observations made about TPs' performances while executing similar blocks of the spatial tasks on the three selected devices are presented. In order to analyse the TPs' strategies, the types (zoom in, zoom out and pan) and amount (count) of interaction activities that each TP made on each device were taken into account. Only interactions done with the maps presented on the screen were considered (i.e. mouse clicks and scroll wheel moves on desktop setting, fingers' pinches and taps on the touch screen settings). Hence, other activities like entering text and hitting buttons were not counted. These observations are discussed below, first: task-wise, then time-wise.

### 5.3.1. Analyzing the results task-wise

In **Task 1**: TPs were asked to use Google Maps® to plan a route from a source city to a destination city, get directions and check the results. This task requires the TPs to interact with the map on the display to get an overview of the whole route. For that purpose, all TPs didn't have to interact with the map presented on the desktop screen. Figure 5-3 illustrates the type and amount of interactions TPs did on the tablet and the smartphone for solving task 1. Clearly one can see that no zoom in was required at all since TPs are not looking for details in this task.

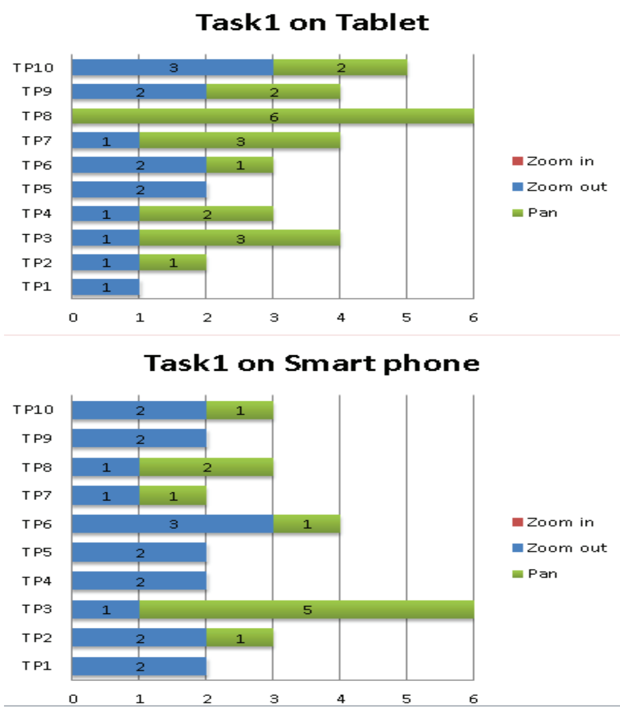



**Figure 5-3: Types and amount of interaction for Task 1**

*(The numbers on the bars represent the count of interaction activities)*

In **Task 2**: TPs were asked to find a city on the planned route to stop at for a break after driving half the way from the starting point (the source city). This task demands that the TPs should keep an overview of the complete route to decide where approximately its middle was, and also in the same time interact with the map to get details and find out the name of a possible city to stop at. Figure 5-4 shows the interactions made by each TP to solve task 2 on each display device. More than half of TPs didn't have to interact at all with the map when using the desktop since its big screen helped them achieve the task easily. On the other hand, zooming - in occurred most often on the smartphone, and by all TPs, because they had to go more into details on such small screen.

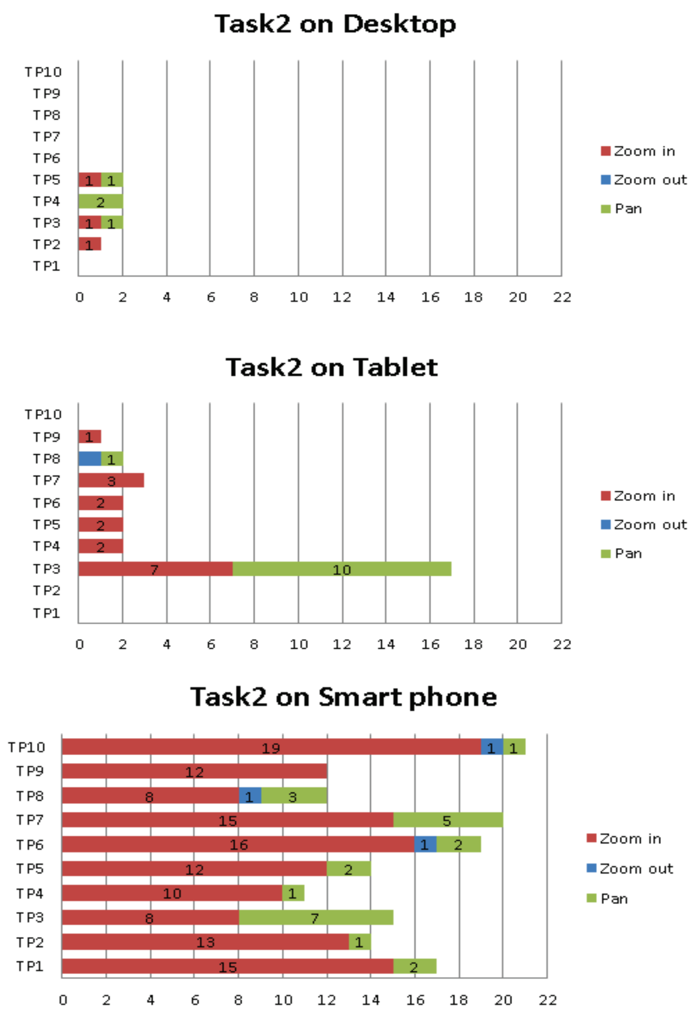



**Figure 5-4: Types and amount of interaction for Task 2**

In **Task 3**: to avoid driving inside the city, TPs were asked to park their cars before entering the centre of the distension city. They were asked to find a suitable commuter train station since such type of stations often has parking lots nearby. This task requires the TP to search for specific objects on the map ,make comparison between possible solutions and then choose a station that best meet the search criteria in his/her opinion. To solve such a task, the TP has to interact with the map on the display by panning, zooming in and out until the task requirements are fulfilled. From Figure 5-5, one can see that among the three types of interaction activities, zooming-in occurred most often due to the need for going into details to solve such task. Zooming-out happened more often on the smartphone, possibly because the TPs had to move quite often back and forth between the zoomed in and zoomed out positions. Panning also was needed most often on the smartphone, probably because its limited screen doesn't show enough content of the map at once.

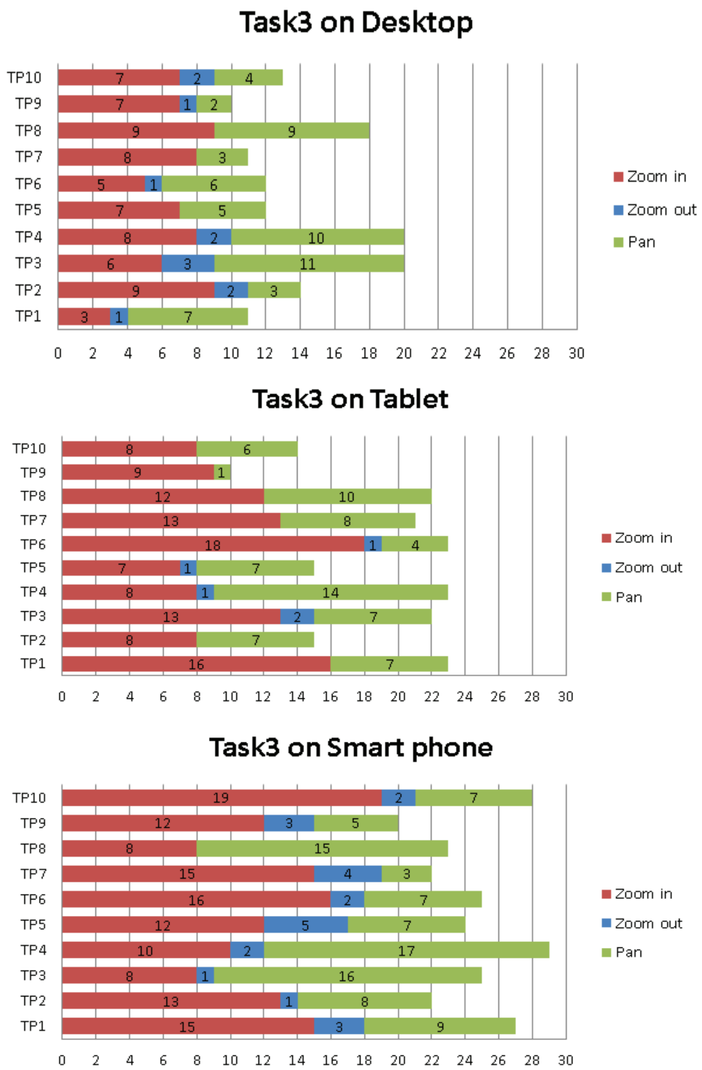



**Figure 5-5: Types and amount of interaction for Task 3**

In **Task 4**: the TPs were asked to find walking directions from point A to point B in the destination city. They had to figure out in which direction they will be walking in order to go from A to B. Solving this task demands the TP to have a sense of orientation while getting an overview of his/her route from point A to point B. Since this task is slightly similar to task 1 in terms of finding direction between two points and getting an overview of the whole route on the screen, the TPs didn't do any interaction on the desktop because they managed to see the desired overview and hence decided on the walking direction. With the exception of a single TP, Figure 5-6 doesn't show much difference between the tablet and the smartphone in the amount of interaction done by the TPs during this task.

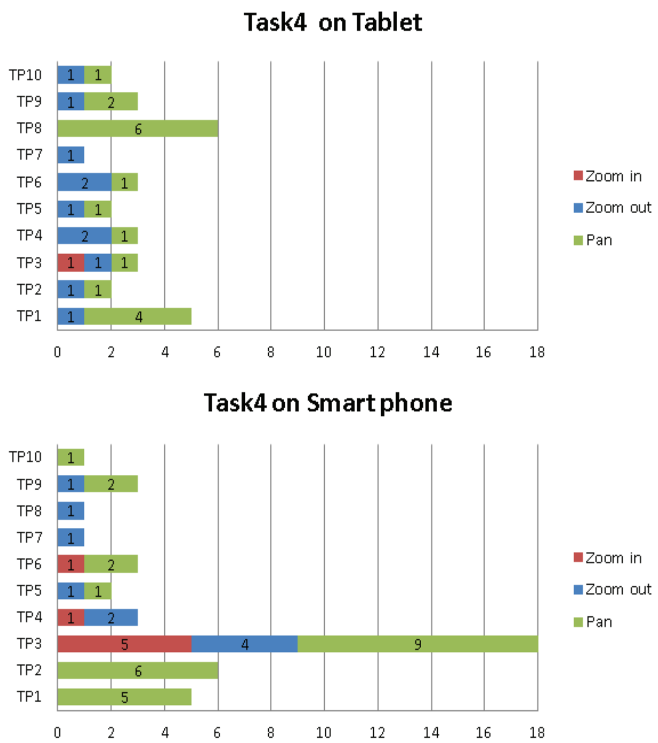



**Figure 5-6: Types and amount of interaction for Task 4**

In **Task 5**: and upon completion of task 4, the TP was asked if he/she wants to reconsider the station where the car was parked at in task 3. This task requests the TP to interact with the visualized map on the screen looking for a possible new candidate station (that could be considered as a better choice than the one selected in task 3), then make a comparison to decide if he/she would consider changing from the station chosen in task 3. An example of what a TP said during thinking aloud is:

"Since I'm eventually going to reach point B, it makes sense to prefer parking my car in a station near this point so that I can find it nearby me at the end of the trip". Figure 5-7 reveals that for solving this task, the smartphone demanded more interaction activities (of all three types) than the tablet, while interaction on the desktop was least for the majority of the TPs.

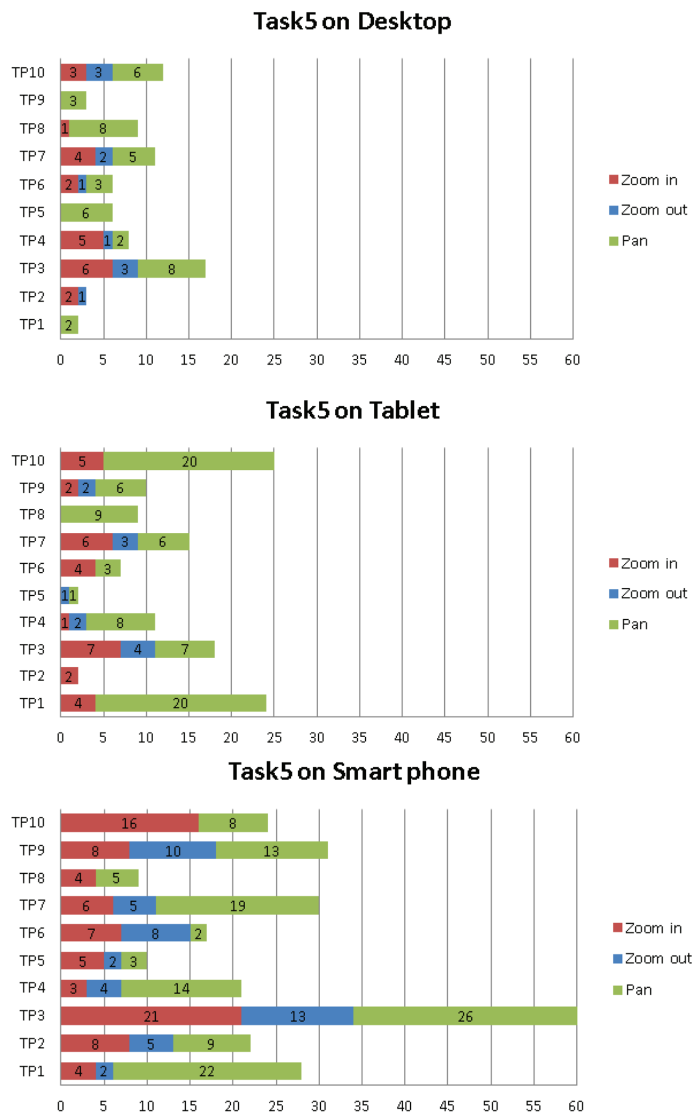



**Figure 5-7: Types and amount of interaction for Task 5**

In **Task 6**: the TP was requested to use the animated map in The Weather Channel application® to find out if the rain is expected on the route while he/she is driving from the source city to the destination city. Since the TPs knew approximately where the source city (Enschede) on the map is located, they tended to consider it as a reference point , enter the name of the city they are going to in the search box, locate that city on the map, then picture the approximate route between those two cities. After that, they played the animation on the map to find out about the rain precipitations in a particular time (time of the trip) and on a particular part on the map (the pictured route). Looking at Figure 5-8, one can easily notice that the smartphone necessitated the largest amount of interaction among the three devices. This is mainly due to the temporal factor involved in this task that made it even harder for the TPs to get the needed information while reading a relatively complex map on such a small screen.

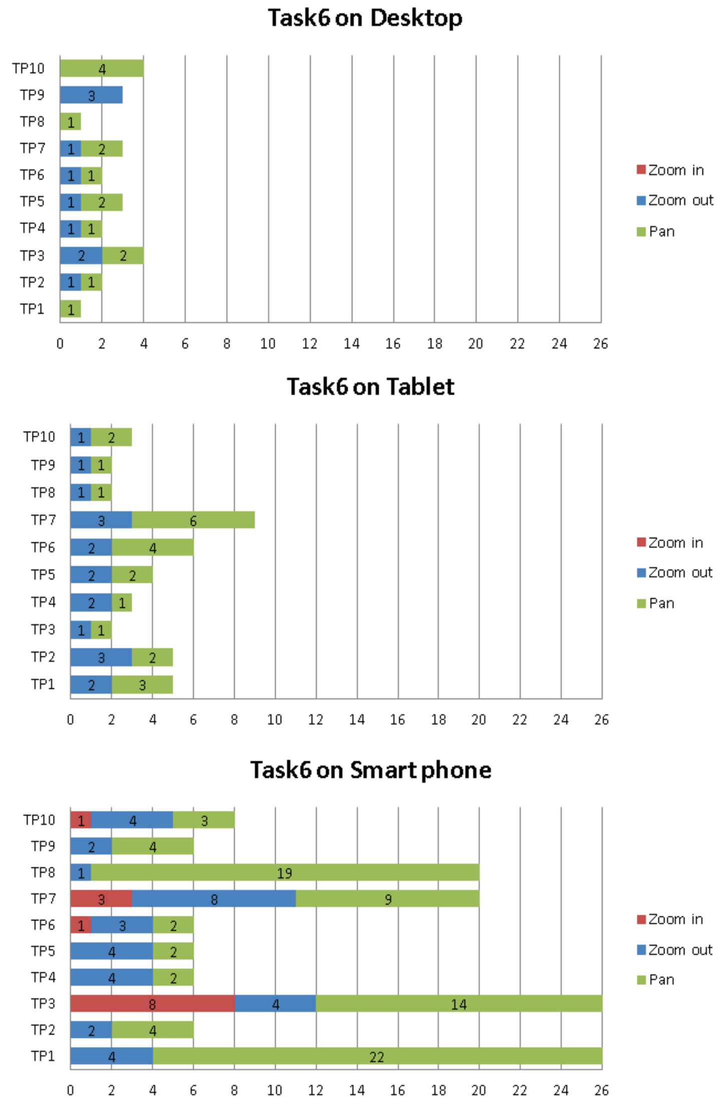
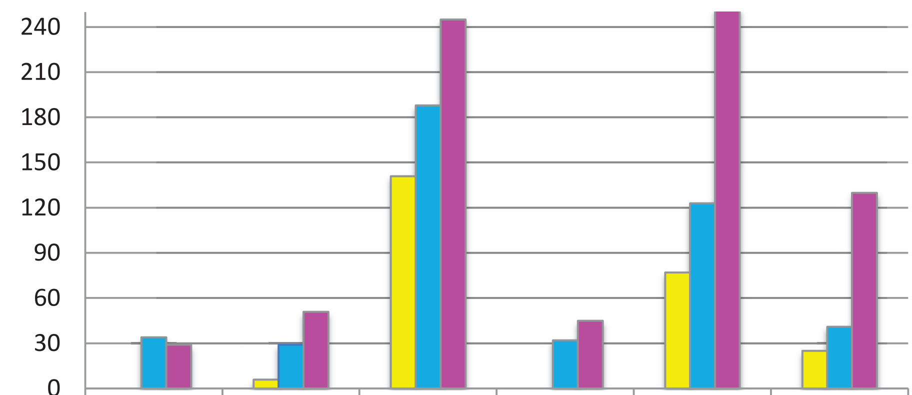



**Figure 5-8: Types and amount of interaction for Task 6**

Up till now in this section, all Figures illustrate how each TP interacted with each display device when solving each task. Next, Figure 5-9 graphs the results for the total amount of interaction activities (count of zooming-in, zooming-out and panning actions) per task of all the TPs for each device.

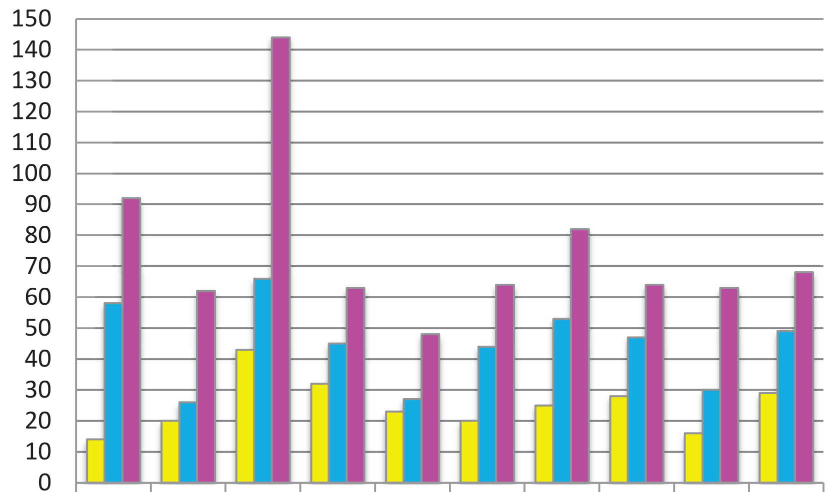



| | task 1 | task 2 | task 3 | task 4 | task 5 | task 6 |
|---|---|---|---|---|---|---|
| Desktop | 0 | 6 | 141 | 0 | 77 | 25 |
| tablet | 34 | 29 | 188 | 32 | 123 | 41 |
| Smartphone | 29 | 51 | 245 | 45 | 252 | 130 |

**Figure 5-9: The total amount of interaction activities per task on each device (Regardless of the TP)**

Regardless of the TP, one can see that for almost all tasks, the smartphone entailed the largest amount of interaction activities followed by the tablet then the desktop where for some tasks (task 1 and 4), no interaction was needed at all. Furthermore, and in relation to Table 4-2, Figure 5-9 shows that tasks that require overview and details (task 3 and task 5) scored the highest numbers of interaction activities, followed by task 6 which involves a temporal factor. The amount of interaction was at minimum for solving tasks that demand overview mostly (task 1 and task 4).

From another point of view, this time regardless of the tasks, results for the total amount of interaction activities each TP made on each device are revealed in Figure 5-10. Again, it is apparent that the smartphone requires most interaction activities for all the TPs. Tablet comes in the second place, while each and every TP did the least number of interactions when the desktop was used.




| | TP1 | TP2 | TP3 | TP4 | TP5 | TP6 | TP7 | TP8 | TP9 | TP10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Desktop | 14 | 20 | 43 | 32 | 23 | 20 | 25 | 28 | 16 | 29 |
| Tablet | 58 | 26 | 66 | 45 | 27 | 44 | 53 | 47 | 30 | 49 |
| smartphone | 92 | 62 | 144 | 63 | 48 | 64 | 82 | 64 | 63 | 68 |

**Figure 5-10: The total amount of interaction activities per TP on each device (Regardless of the task)**

#### 5.3.2. Analysing the results time-wise

Time to complete the tasks is considered as additional information in this study since it is not about testing the usability aspects of a certain website interface or application, what is more important here is to discover differences between users' behaviours and how they communicate with maps on different screen sizes. Figure 5-11 demonstrates results for tasks completion time per TP on each device. Only time spent on solving tasks during the test sessions was measured (i.e. time to read the tasks was disregarded). Comparing the tablet and the smartphone, one can note that differences of tasks execution time between the desktop and tablet and the smartphone and tablet are big; while differences in tasks execution time between the desktop and smartphone are relatively small. Also, it is evident from Figure 5-11 that it took each TP the longest time to execute the tasks using the smartphone. A possible reason for this could be the fact that the TPs on such small screen did more virtual navigation with the map (i.e. did more interaction activities). As the TPs could see less of the map at a time, more virtual navigation was required and consequently more time could be spent to solve the spatial tasks.

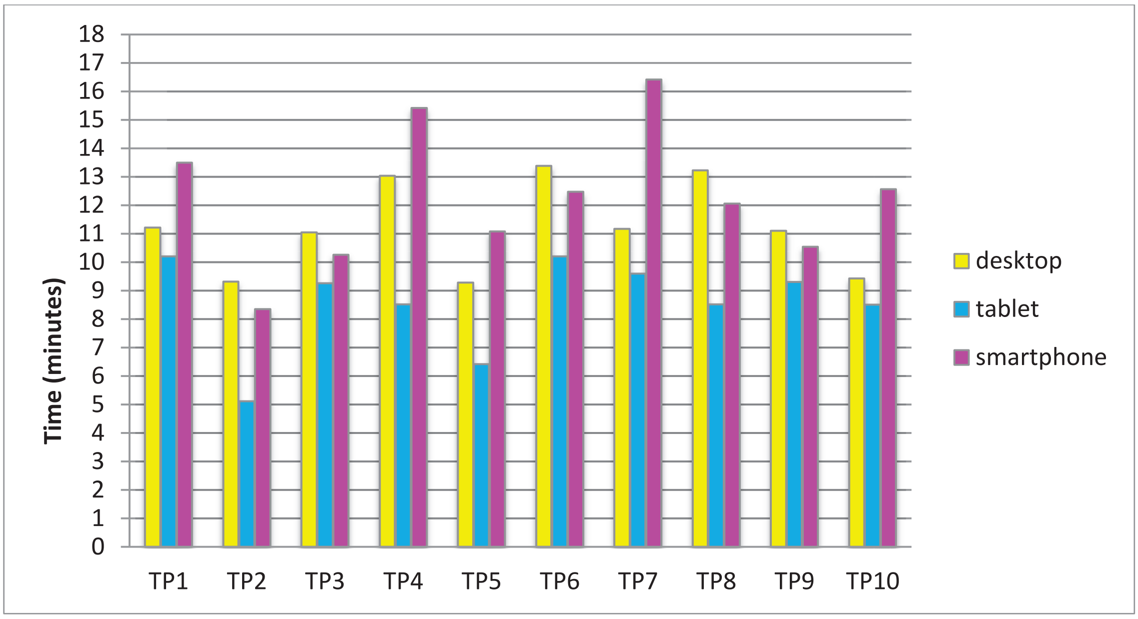



**Figure 5-11: Tasks completion time per TP on each device**

Figure 5-12 shows a graphical representation of average time taken by the TPs to complete the spatial tasks on each device. Average times (in minutes) taken by the TPs for the desktop, the tablet and the smartphone are 11.21, 8.5 and 12.26 minutes respectively.

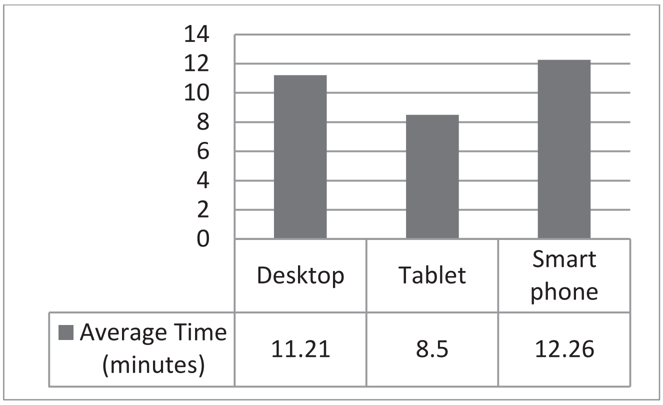



**Figure 5-12: Average times spent to solve the tasks on different display devices**

## 5.4. Results from TLX questionnaires and the post-test questionnaire

In addition to the think aloud, eye tracking and observation methods used during the lab test, different types of questionnaires were distributed during this experiment to collect quantitative and qualitative data from the TPs. Results from the pre-test questionnaire were already analysed in section 5.2. Next to explore is the TLX-Task Load Index questionnaire, which was used to capture the sense of satisfaction from the TP after completing similar blocks of spatial tasks on each display device. This questionnaire was designed in 4-points scale (Not at all, Slightly, Moderately, Very) to make its questions about all four Nasa-workload dimensions (Mental demand – Performance – Effort - Frustration) easy and understandable so that common users can answer them without difficulty. Five questions were included, four closed-end questions where the TP had to check only one option, and one open question asking about any possibly additional comments a TP might want to add about his/her experience of solving the spatial tasks on the particular device just tested. Thus, in total every TP completed this questionnaire three times: for the desktop, then for the smartphone and finally for the tablet. Results from the TLX questionnaires after each device was tested are presented in Figure 5-13.

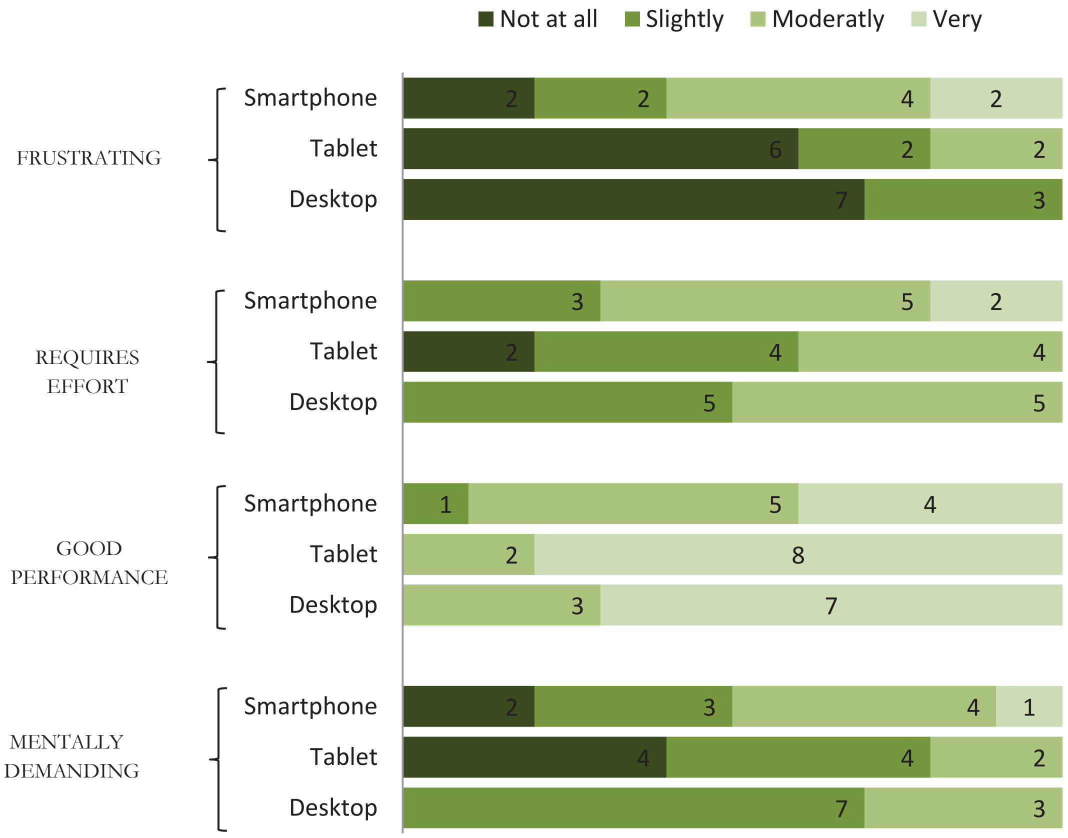



**Figure 5-13: TLX-task load index for using the three display devices**
*(The numbers on the bars represent the count of TPs)*

It is remarkable that the tablet had /8 / TPs feeling that they made a very good performance using it, while only /4 / TPs felt the same using the smartphone. Seven TPs didn't feel frustrated at all using the desktop, /6/ felt the same using the tablet, while only / 2/ felt that using the smartphone was very frustrating experience. None of the TPs thought that using the desktop or the tablet is very effort-requiring, while two of them thought so for using the smartphone.

Concerning the open question asked in the TLX questionnaires about personal annotations from each TP about the tested display device, Tables 5-2, 5-3 and 5-4 show the collected comments from the TPs on using desktop, smartphone and tablet correspondingly.

| TP | Comment |
|---|---|
| 3 | "It was efficient to perform the required tasks on this device, I didn't have to strain to look for a place; it was easy to see with this wide screen." |
| 9 | "I think it's a very good display device to carry out this type of tasks" |
| 10 | " It's comfortable to execute tasks on this device since I'm used to work on it" |

**Table 5-2: TPs' comments after using the desktop**

| TP | Comment |
|---|---|
| 1 | "It's hard to navigate the map on such limited screen; I found myself lost and disoriented many times" |
| 3 | "In task 5, when I tried to find the station where I parked my car, I had to do a lot of zooming and panning due to the small visible space of the map on screen. Eventually, I think I lost context and I couldn't find the place I'm looking for" |
| 4 | "Because of the limited screen, the whole route cannot be seen with details at once, so I had to do zooming and panning quite often to find detailed information " |
| 5 | "Thanks to the touch screen ,using this device was easier for me than using the desktop with its mouse and keyboard" |
| 7 | "When I tried to reconsider the parking I chose, I couldn't remember where it was so I felt lost" |
| 8 | "Small screen in the smartphone led to multiple zooms in and out. Also, I noticed that the map responsiveness on this display was slow due to wireless internet connection. That was something quite annoying" |
| 9 | "It was confusing and not really comfortable to plan a trip using maps on such small screen" |

**Table 5-3: TPs' comments after using the smartphone**

| TP | comment |
|---|---|
| 2 | "This device is more flexible and user-friendly than the other two" |
| 4 | "Due to the appropriate screen size and touch technology, it was the easiest device to work on compared to the desktop and smartphone" |
| 5 | "It is a convenient device, makes it easy and comfortable to accomplish this type of tasks" |
| 8 | "The moderate screen size was good enough to do the tasks securely, better connection speed than smartphone which means quick responses of zoom and pan activities on the map" |
| 9 | "The tablet is much better than the smartphone in terms of the screen size which enabled me to visualize a bigger extent of the map at once" |

**Table 5-4: TPs' comments after using the tablet**

Upon completion of solving tasks on each display device, a post-test questionnaire was distributed to all TPs. This questionnaire aimed at comparing personal impressions each TP had at the end of the tests after trying all three display devices. Results about those impressions regarding the four Nasa-dimensions are specified in Figure 5-14.

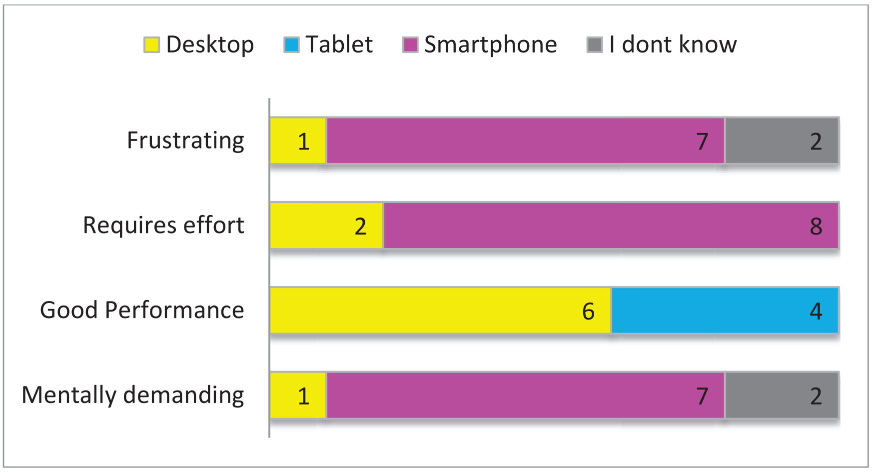



**Figure 5-14: Device Comparison**

*(The numbers on the bars represent the count of TPs)*

Strikingly, the results indicate major differences between the tablet and smartphone for all four dimensions. It is clear from Figure 5-14 that using the smartphone tended to be most frustrating, most mentally demanding and most effort-requiring. None of the TPs felt that good performance was achieved using the smartphone, while six of them gave credits in that matter for the desktop.

Furthermore, the post-test questionnaire asked the TPs to give ratings for using the selected map applications (Google maps and The Weather Channel) on the three selected display devices. Figure 5-15 illustrates how using those applications on each device was ranked with respect to: quickness, effectiveness, mental demand, and ease of use. From this figure, one can see that the majority of the TPs think that using the applications on the desktop was very quick, effective and easy, while half of them think that using those applications on this device was not mentally demanding at all. Coming close behind the desktop is the tablet in terms of easiness, effective and quick performance. While none of the TPs think that using the applications on tablet was very mentally demanding, four of them think so about using the smartphone. More than half of the TPs think that their performance using Google maps and The Weather Channel applications on the smartphone was only moderate in terms of quickness and effectiveness.

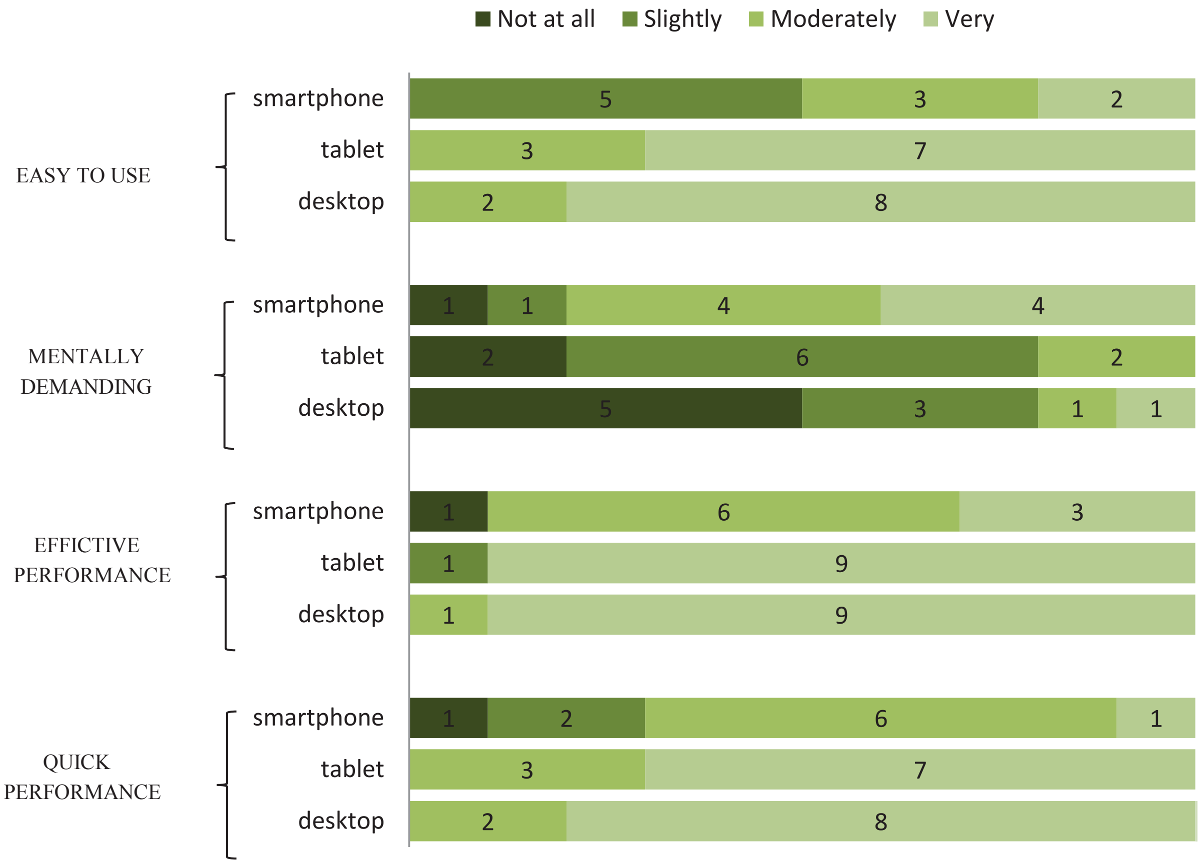



**Figure 5-15: TPs' responses about using the selected applications on the selected display devices**

*(The numbers on the bars represent the count of TPs)*

## 5.5. Results from the Interviews Conducted With TPs

Interviews data was collected primarily to acquire TPs' impressions that might not have been expressed through the other data collection methods. As a result, responses from the interviews helped validating the findings of this study. The questions in the interview were open-ended which encouraged the TPs in explaining their views in depth after testing the three devices. This section indicates how ten TPs generally felt about the whole experiment, and how their responses to the questions varied.

In response to **Question 1**, which was: how enjoyable was the experience of using each device? Half of the TPs answered in favour of the tablet and half in favour of the desktop, while apparently none of them enjoyed using the smartphone. Table 5-5 quotes statements made by the TPs answering this question in the interviews. When some replies from the TPs were very similar, they were combined together in the same table cell.

| TP | Statement |
|---|---|
| 1 | "I enjoyed using the desktop, due to its big screen which allowed me to execute the tasks properly". |
| 2,3 | "Using maps on the tablet was enjoyable, it's user-friendly, its more flexible due to the touch screen which is reasonably big enough. The least platform I enjoyed using maps on was the smartphone because I found the screen too narrow to see the details clearly". |
| 4, 5, 10 | "The tablet was the most enjoyable experience for me due to its appropriate screen size, and touch display is easier and faster to interact with". |
| 6 | "Starting from the most enjoyable to the least, my ranking is: 1st - desktop, 2nd – tablet, and 3rd - smartphone. Desktop is my first preference because I'm more familiar to work with it". |
| 7 | "I enjoyed desktop experience the most. Since I have no experience with touch displays, I didn't feel really comfortable doing tasks on the tablet nor the smartphone, yet I found that using the tablet was less stressful compared to using the smartphone". |
| 8 | "Desktop was the most enjoyable experience to me, mainly due to the big screen that gave me the ability to keep a bigger content of the map visible at a time. That screen also made me feel more free and confident to interact with the map displayed on it". |
| 9 | "I enjoyed desktop the most. It was quite hard for me to see the whole route and its details on the smartphone screen, so I had to do lots of zooming in and out, and consequently I lost context and felt irritated". |

**Table 5-5: The TPs' responses to Question 1**

**Question 2** explored the overall likes and dislikes each TP had after using the three displays. In general, the TPs agreed on the benefit of the big wide screen of the desktop, and on the attractive touch technology in the smartphone and tablet. Though those two devices are portable, the relatively small size of their screens is still considered as a limitation by some TPs. Table 5-6 describes how TPs responded to this question in the interviews.

| TP | Statement |
|---|---|
| 1, 5, 9, 10 | "Desktop has a big wide screen, reading maps on it is more controllable due to the standard input devices (mouse and keyboard), but I can't have this device with me anywhere and anytime. Smartphone is portable yet it has small tiring screen". |
| 2 | "About the desktop, I like the standard input devices which enable more control on the device. An advantage of the tablet and the smartphone is the touch display, it is more dynamic, flexible to use both hands on it, and one can rotate it to have a better view of what he is doing. The tablet's virtual keyboard is big enough to enter text, unlike the smartphone's". |
| 3, 8, 4 | "With the desktop, one can see more in one glance. The touch screen in the tablet makes it more fun to use, and its size is fair enough to see the details. Portability is a benefit of the smartphone, yet dealing with its small screen involves considerable amount of time and concentration". |
| 10 | "A drawback in using the smartphone is that one needs to move a lot on such small screen and do lots of interaction, especially for someone with imperfect vision like me". |

**Table 5-6: The TPs' responses to Question 2**

**Question 3** investigated how types and amounts of interaction activities differed among the three displays while executing the spatial tasks. A unanimous response was obtained for this question declaring that the smartphone requires the biggest amount of interaction activities due to its limited narrow screen. More notes on the focus of this question are mentioned in Table 5-7.

| TP | Statement |
|---|---|
| 1, 3 | "Small screens require more interaction to get details (like the names of the stations) and that is a bit annoying. On such screens, it was harder to see an overview of the whole planned route". |
| 4, 10 | "Less interaction was needed on the desktop, since one can manage to get overview and details. On the tablet, it was moderate. On the smartphone, more zooming and panning were required". |
| 5 | "I found that the touch screen in the tablet was faster to interact with than a screen with mouse and keyboard. Thus, using the desktop demanded more time spent on interaction". |
| 7 | "The amount of interaction is surely different among the three displays. The desktop required less so one can perform the tasks faster. On the smartphone, more effort was done to interact with it, and hence more time was needed for the tasks execution. On the tablet, the amount of interaction was adequate". |
| 8, 6 | "On the desktop, it was easier to move around and zoom in and out. It was almost equally easy on the tablet, but it was rather harder and tense to interact with the maps displayed on the smartphone to get the needed information". |

**Table 5-7: The TPs' responses to Question 3**

**Question 4** inquired the TPs' opinions about the role of the screen size and how it affects spatial task performance. Except for TP5, all TPs agreed that the screen size plays an important role in determining the spatial tasks productivity. More explanations regarding this issue are shown in Table 5-8.

| TP | Statement |
|---|---|
| 1 | "Yes, the screen size matters. The extra screen size of the desktop means that I'm more relaxed and confident doing exploratory tasks. On the smartphone, I can only do targeted and focused tasks". |
| 2, 8 | "Main role, but when one is not doing a big analysis that requires lots of computing resources, tablet is a very good display device to plan a trip. So, to some degree, the screen role depends on what types of tasks one is doing on it". |
| 3 | "Definitely! The bigger the screen, the better the performance. Screen size should be taken into account along with the interface design when assessing spatial tasks performance". |
| 5 | "I don't think screen size play important role. Even with the smaller screens, I think I still can use them well to some efficient level". |
| 6 | "Between the tablet and the desktop: I don't see a big effect of screen size. Between the tablet and the smartphone: I prefer the tablet in terms of the screen size". |
| 7, 4 | "Yes, screen size is a key factor in influencing the spatial task performance, besides other factors like previous experience with using maps and with using the display device". |
| 10 | "Screen size is important indeed. I think reading maps using smaller screens would be somewhat problematic". |

**Table 5-8: The TPs' responses to Question 4**

In **Question 5**, the TPs were asked to comment on the difficulties they encountered in using Google maps® and The Weather Channel® application on each of the display devices to solve the spatial tasks. Several issues were expressed here like the text entry, speed of internet connection, and the temporal factor associated with reading the weather maps. Further notations in response to this question are stated in Table 5-9.

| TP | Statement |
|---|---|
| 2 | "Entering text in virtual keyboard on smart phone was cumbersome". |
| 3 | "Due to the temporal factor, I found that the animated weather maps were not clear to neither read nor understand, especially on smaller screens. When playing the animation on the map, one doesn't get to know about how the exact weather condition will be in a certain area at a certain time; one can only speculate". |
| 6 | "Wireless internet connection speed on the portable devices is normally slower than cable connection on the desktops. I felt frustrated while waiting to see all parts of the map being loaded on the screen". |
| 7, 10 | "It was pretty harder to find details on smaller screens, like searching for points of interests on the map and read their names". |
| 8, 4 | "I struggled to get the needed information from the animated weather maps. The temporal factor makes it even more complex to read such maps on smaller screens". |
| 9 | "I'm familiar with using Google maps so all went smooth, though it was a bit challenging for me to type (enter text) on smaller screens". |

**Table 5-9: The TPs' responses to Question 5**

**Question 6** acted as a sequel to the question asked before in the pre-test questionnaire about what display device a TP would choose to perform a set of spatial tasks if he/she was in a room where the three devices are available. Each TP was asked this question again during the interview to see if he/she would change their first choice made before testing the three display devices. Interestingly, the 2 TPs who picked the smartphone in the beginning have changed their minds to choosing the table. Moreover, the same six TPs who preferred using the desktop in the first place have kept their choice the same after testing all the three devices.TP 1 and TP 7 who have no experience with using touch screens, kept their initial choices in favour of using the desktop, while TP 4 and TP 8, who are well experienced in using touch screens, changed their early picks from the smartphone to the tablet (and not to the desktop) at the end of the experiment. See Table 5-10 for more related notes.

| TP | Statement |
|---|---|
| 2, 10 | "Actually, It depends! If I'm in the office, I would still choose desktop for the screen size and input devices. If I'm Outside the office, I would choose tablet. Smartphone will always be my last choice". |
| 3 | "My 1st choice was tablet and it remains the same as my 2nd Choice, But between the desktop and smartphone, I would certainly choose the desktop". |
| 4 | "My 1st choice was smartphone. After doing the experiment, I would change my mind to choose the tablet. Now I prefer it more due to its bigger screen size". |
| 5 | "My 1st and 2nd display device to select is tablet." |
| 6 | "My 1st and 2nd pick up is desktop, always! After doing the test, I still prefer it the most, then tablet comes next. But I didn't like using maps on the smartphone at all" |

| | |
|---|---|
| 1, 7, 9 | "Without hesitation, I would always choose the desktop for such purpose of solving spatial tasks". |
| 8 | "At the beginning, I picked up the smartphone.at the end of this test; I would say that I'm changing my mind to pick up the tablet. I saw a trade-off between how effective and portable the tablet is and how big the desktop screen is". |

**Table 5-10: The TPs' responses to Question 6**

To sum up, most TPs were pleasantly surprised by the enjoyment of using the tablet, saying that it's fun to interact with its touch screen. They think that its screen is fairly big to read maps properly, unlike the restricted screen in the smartphone which is tiring and quite hard to deal with. Many TPs had troubles in typing correctly on the smartphone reporting that they accidentally hit wrong links and buttons, they felt that typing using the standard keyboard in the desktop was very easy and natural. Overall, most TPs were satisfied with using the desktop due to its big screen that enables better overviews, they think that this display device is the best for in depth exploratory spatial tasks, followed by the tablet, then the smartphone which was largely unsatisfying to use due to its small limited screen that demands more interaction, and also because of the slowness (delay) encountered in map loading time.

## 5.6. Observations With Regard To Eye-Tracking Data

Using the eye tracking methodology in this research was advantageous since data about eye gazing made clear at what parts of the screen the TPs looked at, and most importantly, what parts of the screen the TPs looked at to find answers to their geographical questions. The data collected by the eye tracking approach enabled the analysis of several aspects of a TP's behaviour including elapsed time and virtual navigation on the screen (i.e. interaction activities like zooming and panning). Naturally, TPs looked at different parts of the displayed map, but since the map window shown on the screen was constantly changing due to the zooming and panning activities, heat maps generated for eye gazing were not really very useful, simply because the TPs eyes during this test were moving all over the displayed map and not fixed on specific locations for long periods. Yet, effort was made to generate heat maps during segments where the map window was relatively stable.

For the analysis, all the recordings were played back, making notes of them and making use of heat map feature in Tobii® software, it has been noticed that with the three display devices tested, the TPs tended to get an overview of the route planned with Google maps® by making it visible as a whole on the screen. Gazing focuses at the start and end points of this route (see Figure 5-16).

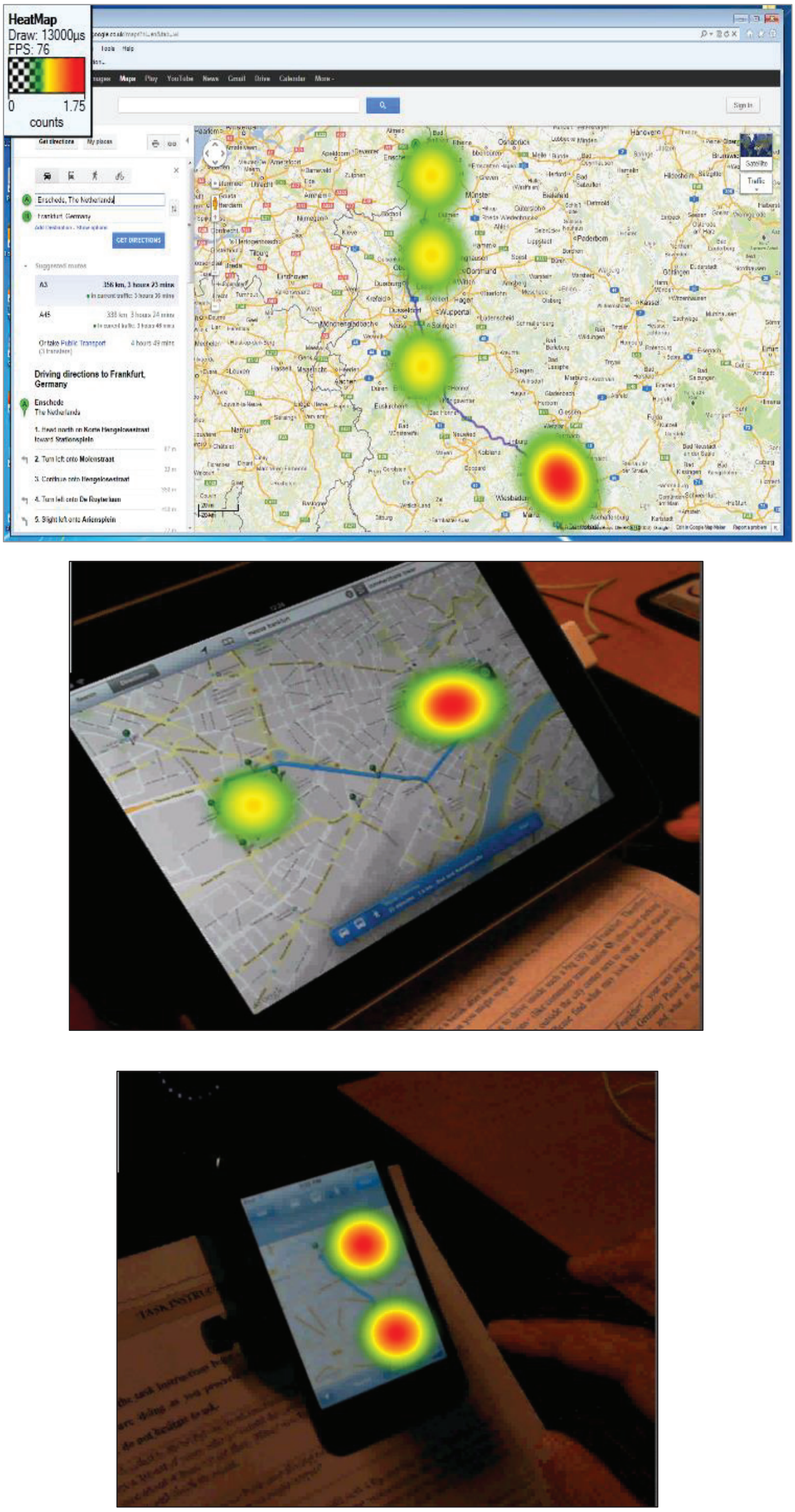



**Figure 5-16: Heat maps show where the TP look at on the planned route when using the screens of desktop, tablet and smartphone**

Moreover, when TPs were asked to find a specific location (like in tasks 2, 3), they tended to move their eyes all over the map and don't fixate until they possibly find a place that satisfies the search criteria, then they gaze more on the place of focus, and zoom into details in order to find the needed information (See Figure 5-17).


**Figure 5-17(a): Heat map generated while a TP was using the tablet to solve Task 2, which required finding a city half way on the planned route to stop at. In this snap shot, the TP was trying to read the name of the chosen city.**

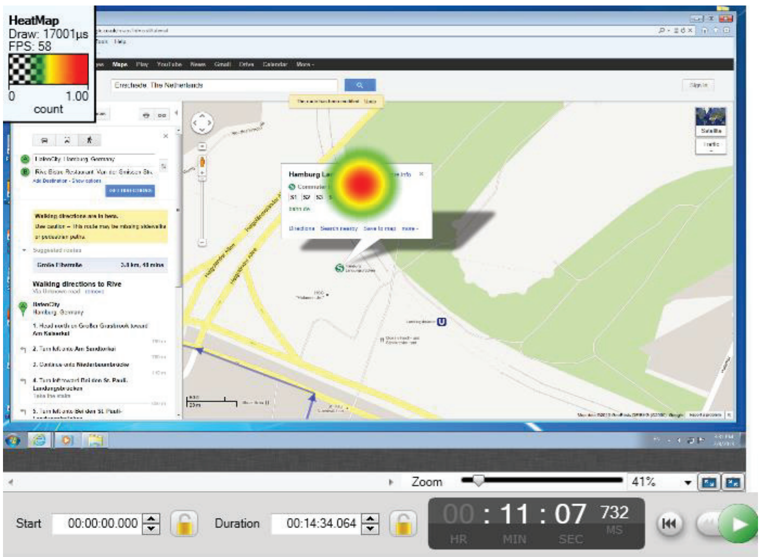



**Figure 5-17(b): Heat map generated while a TP was using the desktop screen to solve Task 3, which required finding a suitable station to park the car at. In this snap shot, the TP has zoomed in to get details about the selected station.**

With the Weather Channel® application, the temporal factor had to be considered while trying to figure out if rain is expected in an area of focus. Therefore, the TPs tended to look simultaneously at that area and at the moving animation of the radar layer (i.e. the clouds layer) along with watching the changing time bar and the clouds movement so that they could eventually manage to decide if it will be raining or not on a specific area in a specific time span (see Figure 5-18).


**Figure 5-18(a): Heat map generated while a TP was solving Task 6.**
**In this snap shot, the TP was trying to watch the moving animation, look at the area of the planned route, and also keep an eye on the time bar at the upper left corner of the tablet screen.**

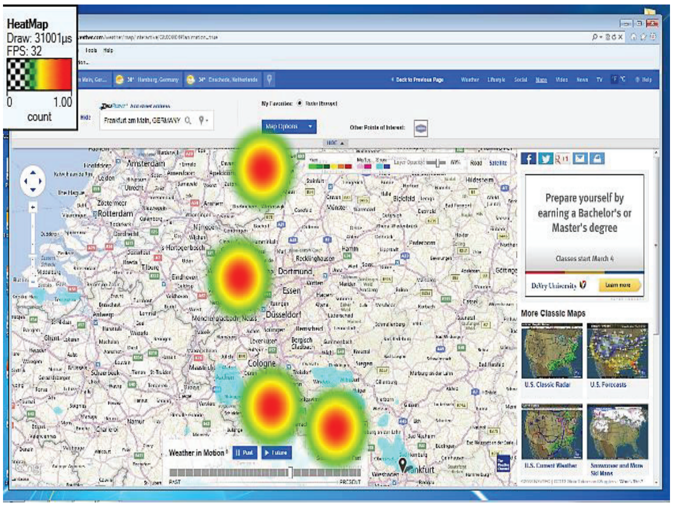



**Figure 5-18(b): Heat map generated while a TP was solving Task 6.**
**In this snap shot, the TP was trying to watch the moving animation, look at the area of the planned route, and also keep an eye on the time bar at the bottom of the desktop screen.**

## 5.7. Conclusion

Through a controlled lab experiment, empirical evidence was provided to show that when screen size varies, spatial task performance varies too. Mainly, this performance was analysed with respect to type and amount of interaction activities and tasks completion time. Examining these factors and others (like prior experience with touch screens) begins to address questions regarding user behaviour with maps displayed on different screen sizes of computing devices. In this chapter, the findings indicated a relatively big difference between the smartphone and the other two devices regarding the required amount of interaction. The majority of the TPs felt that they worked harder, performed poorer and were more frustrated when using this device. The tasks completion time data revealed big differences between the tablet and the other two devices, while this data did not reflect a major difference between the desktop and the smartphone. A possible explanation for why using the desktop to solve the tasks took more time than using the tablet could be that using standard input devices (e.g. mouse clicks and keyboard strokes) for interaction with the desktop screen takes more time than using fingers gestures (like tap and pinch) to interact with the tablet display. In other words, a trade-off should be made between the wide screen with controllable yet slow input devices on the desktop and between the relatively small, yet quick and attractive to manipulate touch screen on the tablet.

In the next chapter, discussion about the results presented in chapter 5 is established, followed by an overall conclusion derived from those results; summarizing the work that is done in this study.

# 6. DISCUSSION, CONCLUSION AND FUTURE WORK

Based on existing knowledge, and in order to reflect on the research questions presented earlier in chapter 1, this chapter recaps on the experiment's findings and interpret them with respect to the research hypotheses. Moreover, it highlights some general observations and portrays what still need to be done in the future.

## 6.1. DISCUSSION

Previously in chapter 1, a hypothesis was made that there is a measurable difference in the performance of similar spatial tasks across three devices; a device with smaller screen (smartphone) would increase the required amount of interaction the user has to do in order to see sufficient information. As a result of having more zooms and pans, mental effort and hence task execution time would increase as well. Moreover, it was assumed that users would have a preference for bigger screens over smaller ones. The smartphone was expected to be the least preferred device, while there was uncertainty whether the desktop or the tablet would be the TPs' favourite. Effort was made to find evidence in the data collected for each hypothesis. Focus was mainly on how the TPs interacted with the map on the display device. Despite that only 10 TPs participated in this experiment, it has been noticed that those TPs performed differently to some extent. Not only was the performance different among the TPs using the three displays, also satisfaction and personal preference varied from one TP to another. The obtained results support the assumption that interaction is required the most with the smallest screen and the mental effort is considerably connected to screen size. However, it was not always the case that "task execution time is the longest when display size is the smallest"; as revealed earlier, it took all the TPs the shortest time on tablet to solve the tasks compared to the time spent on the desktop and on the smartphone. Table 6-1 shows a summary of effects that were concluded from the findings:

| Effect | Desktop | Tablet | Smartphone |
|---|---|---|---|
| Best insight between overview-level and detail-level | ✓ | | |
| The most mentally demanding | | | ✓ |
| The most frustrating | | | ✓ |
| The quickest performance | | ✓ | |
| The least favoured | | | ✓ |
| Requires the most interaction | | | ✓ |

**Table 6-1: Summary of effects**

During the test sessions in the laboratory, the TPs were observed while performing predefined comparable sets of spatial tasks. Upon replaying all the audio and video recordings, several remarks were noted down as follows:

- The TPs tended to look for an overview because they feel to have more accomplished with an observation that covers a larger portion of area. A small display limits the extent and amount of details that can be represented in a single field of view. In order to change those limits, the TPs tended to pan, and to zoom in or out more often. For example, most TPs managed to see locations' names directly while using the desktop, but for that purpose they had to zoom in more on the tablet, and even more on the smartphone.

- Overall, TPs tended to zoom and pan only when targets were too indistinct to see. One possibility to explain this is that TP didn't like to lose context. When too much panning and zooming is needed to be done, people would lose context and hence get frustrated (as verified earlier in chapter 5).

- Asking for details stimulates interaction, and makes the user change the area of focus frequently. Keeping track of the changing display during zooming and panning requires the TP to remember previous views. While the TPs were executing Task 5: one of them got lost (disoriented) while using the desktop and couldn't remember the location where he had parked his car in Task 3. Therefore, he couldn't compare the current location of his car with other potential locations to solve this task. The same happened with three TP's when they used the tablet to solve this task. When smartphone was used, six TP's lost context and hence were confused. The bottom line here is when the TPs interacted with smaller screens (especially the smartphone), they often became disoriented and agitated. That led to a lower rating for the smartphone which was the least preferred by all TPs at the end of the experiment.

- Typically, the TPs had to interact with maps on the screen by using different controls (provided in the interface of the applications used) for scrolling, panning and zooming (e.g., zoom slider and arrows buttons). It has been observed that the TPs did not like to use these control tools to interact with the maps. Instead, they tended to pan, zoom out to a certain point and zoom in at areas of interest by using mouse clicks and the scroll wheel of the mouse on the desktop configuration ,and by using fingers gestures like (tap and pinch) on the touch screens.

- Some tasks (e.g. Task 1 and Task 4) required the TPs to enter text using the keyboard (real or virtual). For this type of interaction; many TP's (especially who are less familiar with touch screens) reported facing difficulty doing this on the smaller displays since they accidently hit wrong buttons and were more error prone. Preference for the desktop keyboard was mentioned, since most of the TPs filled the text boxes easily using it. Overall, the TPs found that entering text on the smartphone and the tablet made task process more cumbersome.

- On a broader level, a second focus of the experiment was to consider users' performance as related to their previous experience with touch devices, and familiarity with the study area. Testing users with no familiarity with the area against others with higher familiarity might yield differences in the results. Yet, in this experiment, familiarity with the study area did not seem to affect TPs' performance, perhaps because there was no variation in familiarity, since all of the TPs reported no familiarity at all with the study area (except for two with only average familiarity). Experience with touch devices was expected to have an effect on interaction, since those with more experience may be more comfortable in doing zoom and pan, and are more used to viewing a changing display. TP1 and TP7 expressed having no experience at all with touch devices (both tablet and smartphone), while the rest reported modest to very good experience. At large, those two TPs spent more time and did more interaction to complete the tasks on the tablet and the smartphone compared to the rest of the TPs. However, in this experiment, no strong relation was found between the TPs' performance and their prior experiences with touch devices.

- When the TPs were asked to pick one display device if they were in a room with desktop, tablet and smartphone available, none of them cared if the devices were on or off (plugged in or not). In other words, the speed of starting a display device was not really an issue for them. They were more interested in how operational and easy to use a display device is.

- In general, using larger screens was preferred over using smaller ones, since the small ones make it harder to find details on the map, particularly when solving tasks that involve more interaction. An indication was made that the performance could be task-dependent, suggesting that a small mobile device like smartphone could be good enough for solving simpler tasks, while desktop and tablet could be more useful and convenient for solving more complex ones.

- Despite that spatial task performance differed somewhat from TP to another, all TPs managed to complete the tasks assigned to each device properly. However, accuracy of the TPs' answers (i.e. whether they came up with the right answers or not while solving the tasks) was irrelevant to this research, since it is not about how an application or an interface is effective and efficient in delivering information.

## 6.2. Conclusion

Because it is relatively a recent emergence; little research has been done in the area of screen size comparison. While many prior studies have investigated the utility of a given application or the usability of a device, a tool or an interface, less work has been done looking at the performance of spatial tasks across various display devices. Understanding how user interpret digital maps and interact with them across several display devices, and how the interaction varies with different tasks and situations would help presenting appropriate methods of displaying spatial information on different devices, and would contribute knowledge to the study of human-computer interaction and spatial behaviour, information visualization, and map use and usability.

Display size sets a limit on how much data can be comfortably presented at one time. When dealing with limited screens, the entire amount of available information on the map cannot be shown in a useful way at once or with equal focus. Displaying a map in its entirety typically provides only an overview without sufficient detail, while zoomed-in views offer more detail, but cause loss the overall context. Hence, users are required to navigate the map virtually by using zoom and pan functionalities that allow them to select the desired portion of space to be viewed. In other words, geographical tasks involve a spatial context which needs overview and/or detailed information which translates into interaction requirements.
Which spatial tasks do users perform when using maps on different devices with varying screen sizes?
What is the influence of screen size on performing similar spatial tasks across several computing display devices? What factors are involved, and how might they be measured and addressed?
To what extent does screen size contribute to mental effort? And how does it affect the type and amount of interaction, task completion time, and individual preference and satisfaction?
This research made an attempt to find answers to such questions in order to achieve its main goal, which is twofold: on one level, it sought to know more about the user interaction and behaviour with devices having different screen sizes and, on a broader level, to define the relationship between screen size and spatial task performance in terms of: task load, task execution time and subjective satisfaction and preference.

For that purpose, a laboratory experiment was conducted to compare map using experiences of ten TPs when performing typical common spatial tasks across desktop, tablet and smartphone. Three similar forms of spatial tasks were prepared to ensure that testing tasks for the three devices are comparable. The time and interaction spent to solve the tasks on each device were distinguished. Several different questionnaires were administered throughout the experiment. At the end, interviews with the TPs were held to get their comments and feedback.

Since it was essential in this experiment to observe the TPs while they are browsing maps on the three selected devices trying to get an overview and /or details, using only questionnaires and interviews would not provide sufficient data. Therefore, think-aloud and video recording with eye-tracking methods were employed, and proved to be suitable and beneficial.

By reviewing all the results from the lab test, questionnaires and interviews, and in order to address research questions previously posed, a conclusion can be made that screen size has impact on the presentation and exploration of spatial data, it has been noticed that different display devices do encourage different user behaviours when dealing with maps. Thus, screen size plays a role in spatial task performance. These results suggested that the smaller screen prompted the TPs to use more zoom and pan activities in attempting to get information to solve the tasks. i.e., zooming in and out and panning were more often required with smaller displays than bigger ones; since the visualized map would inevitably be larger than the extent that can be viewed at one time. It has been found that bigger displays can be advantageous in improving performance when helping people reading maps faster with less interaction required. Though it was not unanimous, two-third of the TPs preferred the use of desktop, commenting that it was easy to use and familiar.

On the other hand, with screen size being a limiting factor, the smartphone appeared to be the hardest to use, the least effective, and it demanded most mental effort compared to the tablet and desktop. That comes in agreement with the hypothesis saying that using smaller screens would result in more browsing (i.e. more interaction).

The findings indicated that the tablet outperformed all other displays in terms of the time spent to solve the tasks. Eventually, the desktop was the favourite display for more than half of TPs (6 TPs) while the rest showed preference for the tablet. The latter was preferred over the smartphone because it is fairly easy to use, attractive and fulfils users' requirements. Using tablets has proved that the advent of more intuitive and appealing interaction through touch-screen may bridge a big gap for task performance on the small screen devices. Overall, it was surprising to find that the tablet was considered to be relatively equivalent to the desktop despite a slightly smaller screen. Most TPs indicated that the desktop and the tablet were nearly equal (with the tablet coming close behind the desktop). Since performance on the tablet was better than expected, many TPs enjoyed using it; they were content to have a fairly commensurate experience between tablet and desktop.

## 6.3. Future Work

There is still a large area of research that can be done to improve our understanding of how human behaviour changes with various screen sizes. For example, how do different pixel resolutions and densities affect human behaviour and performance? Additional elements critical to consider for maps on display devices include how map use is affected by individual factors and differences such as spatial abilities, gender, age, familiarity with an area, visual impairment and map experience. Moreover, and along with the effect of screen size, future work should be done on to realize how different levels of complexity in the executed spatial tasks would influence the user's performance.

As users' needs develop and mobile devices mature, the spatial tasks performed with them will become increasingly complex. An important area of future work is to investigate the relationship between task complexity and users performance when using different sizes of screens.

Wobbrock (2006), as cited in Marcial (2012), suggested that we are no longer just investigating the capability of any single device (or even a group of devices); instead, we now need to consider context in addition to capability., since Mobile phones and tablets are used in the real outside world where maps are used for field-based activities such as navigation, testing handheld devices should not only take place in a laboratory. It will be interesting to do this work in a more realistic out door context where the user's cognitive resources for any given task are divided due to distractions, physical movement and concurrent tasks.

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URL19: http://support.apple.com/kb/sp565
(Last Accessed Oct 15, 2012)

URL20: http://www.tobii.com/en/eye-tracking-research/global/products/hardware/tobii-x60x120-eye-tracker/
(Last Accessed Feb 26, 2013)

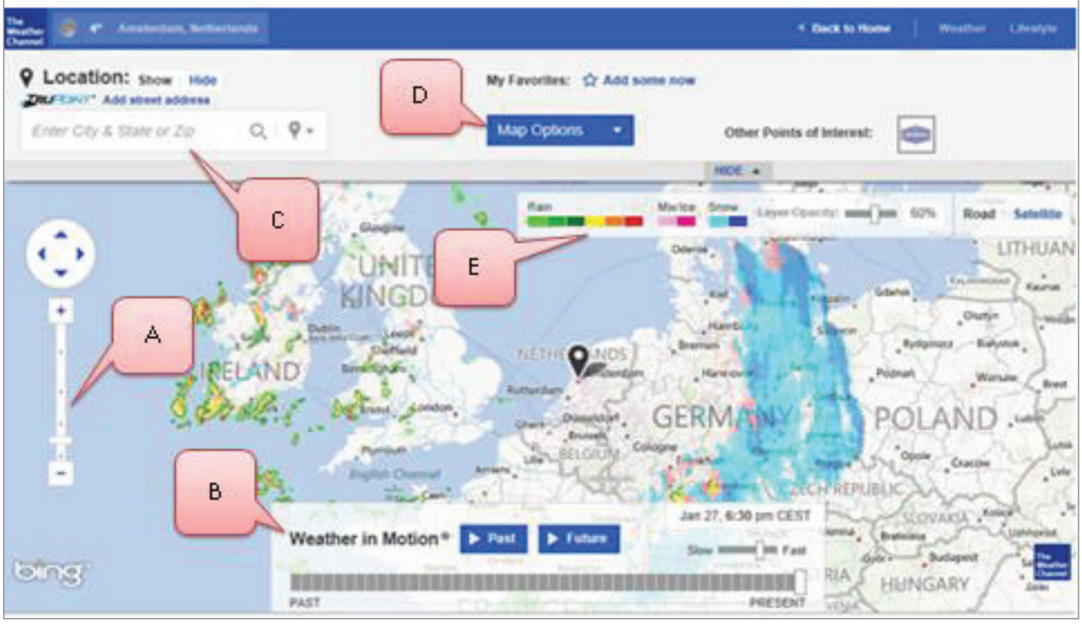
URL21: http://www.tobii.com/en/eye-tracking-research/global/products/hardware-accessories/tobii-mobile-device-stand/
(Last Accessed Feb 26, 2013)

URL22: http://www.tobii.com/en/eye-tracking-research/global/products/software/tobii-studio-analysis-software/
(Last Accessed Feb 26, 2013)

## **Appendix (A):** The Weather Channel® Quick Guideline

**What information can be seen on the map?**

a wide variety of weather information, ranging from radar imagery to temperature plots. This interactive map shows moving precipitation in the selected area.




**A** How to interact with the map to change your geographical viewpoint?

**Zooming:**

1. Move the slider control on the left side of the map up for a tighter view and down for a wider perspective.
2. Double click on the map to zoom in (tap with tablets).
3. Rotate your mouse wheel forward/backward to zoom in/out.

**Panning:**

1. Click on the radial arrows above the zoom slider to move map in corresponding direction.
2. Hold down the left mouse button and drag the map to shift location (touch with tablets).

B

## How to view Weather in Motion?

- Click the Play button in the animation control box at the bottom of the map to put weather in motion for most image layers. The default timeline cycles through past (actual) conditions with varying time intervals. select Future to see conditions expected for the next few hours.

- To take more control with animations, pause the animation and grab the slider and adjust to your desired time interval.

C

**Searching a New Location?**
Above the top-left corner of the map, enter any city to re-center the map on your desired location.

**Choosing Layers**
From the "map options" you can choose which layers to view on the map, for example:

D

**<u>radar layers</u>**

These layers indicate type and intensity of precipitation for various geographical areas(e.g. North America, Europe, Australia).click the play button down the map to see movement of precipitation over time.

**<u>Satellite layers</u>**

These layers indicate cloud cover for various geographical areas. Taller clouds are often associated with precipitation. Click the play button down the map to see cloud movement over time.

E

## The radar legend for precipitation intensity

The different colors represent the intensity of the precipitation.

- Green corresponds to lighter precipitation
- Yellow to moderate precipitation
- Orange to heavier precipitation
- Red to heaviest precipitation.
- Light pink corresponds to light freezing rain and/or sleet possibly mixed with rain or snow.
- Darker pink corresponds to heavier icy precipitation.
- Light blue corresponds to lighter snowfall, and bright blue corresponds to heavier snowfall.

## **Appendix (B):** Task Blocks

### TASK INSTRUCTIONS (Block - A)

**Kindly read the task instructions below carefully, remember to 'think aloud' and say what you are doing as you proceed with the task execution. If you find yourself stranded, do not hesitate to ask. Please complete the tasks as you normally would, take the same amount of time and attention that you would if you were performing the tasks on your own.**

| Task No. | Task Description |
|---|---|
| 1 | You decided to drive (by car) from *Enschede* to ***Hamburg*** within an hour from now in order to meet a friend of yours who is visiting this city in Germany for a short trip. It will take you about 3 hours to get there. Please use **Google Maps®** to plan your route and get directions and check the result. |
| 2 | You want to stop to have a break after driving half the way from *Enschede* to *Hamburg*. Which big city you can see on your route that you might stop at? |
| 3 | You know that you do not like to drive inside such a big city like *Hamburg*. Therefore, and giving that public transport stations* (like commuter trains stations ) often have parking lots nearby ,you want to park your car outside the city center area next to one of those stations and then travel further from there. Please find what may look like a suitable public transport station for that. |
| 4 | You will meet your friend in "*Hafencity*" area, the largest urban building project in Europe. Someone has recommended to you a restaurant called (*Rive Bistro*) in the *Hamburg* harbor area, so you and your friend will be taking a walk from "*Hafencity*" to that restaurant. Please find out in which direction you will be **walking** (North-South-East-West), and what is the approximate distance to get there. |
| 5 | Now that you know you are going to eat there, do you want to reconsider the place where you are going to park your car? |
| 6 | You want to know whether rain is expected along the route while you are driving from *Enschede* to *Hamburg*. Please find out about that using the animated map in **The Weather Channel®** website/application. |

* Public transport stations (like commuter trains stations ) are automatically shown on the map (i.e. no need to add specific layers).

**Thank you for completing this part of the experiment!**

## TASK INSTRUCTIONS (Block - B)

**Kindly read the task instructions below carefully, remember to 'think aloud' and say what you are doing as you proceed with the task execution. If you find yourself stranded, do not hesitate to ask. Please complete the tasks as you normally would, take the same amount of time and attention that you would if you were performing the tasks on your own.**

| Task No. | Task Description |
|---|---|
| 1 | You decided to drive (by car) from *Enschede* to ***Berlin*** within an hour from now in order to meet a friend of yours who is visiting the capital of Germany for a business trip. It will take you about 4 hours to get there. Please use **Google Maps®** to plan your route and get directions and check the result. |
| 2 | You want to stop to have a break after driving half the way from *Enschede* to *Berlin*. Which big city you can see on your route that you might stop at? |
| 3 | You know that you do not like to drive inside such a big city like *Berlin*. Therefore, and giving that public transport stations* (like commuter trains stations S) often have parking lots nearby ,you want to park your car outside the city center area next to one of those stations and then travel further from there. Please find what may look like a suitable public transport station for that. |
| 4 | Your friend will be expecting to meet you in front of the "*Deusches Historisches Museum*". Afterwards, you both will be taking a walk towards the "*Reichstag*" building In *Berlin*. Please find out in which direction you will be **walking** (North-South-East-West), and what the approximate distance to get there is. |
| 5 | Lots of restaurants are located nearby the *"Reichstag"*. Now that you know you are going to have dinner with your friend there, do you want to reconsider the place where you are going to park your car? |
| 6 | You want to know whether rain is expected along the route while you are driving from *Enschede* to *Berlin*. Please find out about that using the animated map in **The Weather Channel®** website/application. |

* Public transport stations (like commuter trains stations S) are automatically shown on the map (i.e. no need to add specific layers).

**Thank you for completing this part of the experiment!**

| TASK INSTRUCTIONS (Block - C) |
|---|

**Kindly read the task instructions below carefully, remember to 'think aloud' and say what you are doing as you proceed with the task execution. If you find yourself stranded, do not hesitate to ask. Please complete the tasks as you normally would, take the same amount of time and attention that you would if you were performing the tasks on your own.**

| Task No. | Task Description |
|---|---|
| 1 | You decided to drive (by car) from *Enschede* to ***Frankfurt*** within an hour from now in order to visit a trade fair that is held on the exhibition grounds at the "*Messe Frankfurt*". It will take you about 3 hours to get there. Please use **Google Maps®** to plan your route and get directions and check the result. |
| 2 | 2-You want to stop to have a break after driving half the way from *Enschede* to *Frankfurt*. Which big city you can see on your route that you might stop at? |
| 3 | 3- You know that you do not like to drive inside such a big city like *Frankfurt*. Therefore, and giving that public transport stations* (like commuter trains station Ⓢ) often have parking lots nearby ,you want to park your car outside the city center area next to one of those stations and then travel further from there. Please find what may look like a suitable public transport station for that. |
| 4 | 4-After a long day in the trade fair at the "*Messe Frankfurt*", your next stop will be the *"Commerzbank Tower"*; the tallest building in Germany. Please find out in which direction you will be **walking** (North-South-East- West), and what is the approximate distance to get there. |
| 5 | 5-Lots of restaurants are located nearby the *"Commerzbank Tower"*. Now that you know you are going to have dinner there, do you want to reconsider the place where you are going to park your car? |
| 6 | 6-You want to know whether rain is expected along the route while you are driving from Enschede to Frankfurt. Please find out about that using the animated map in **The Weather Channel**® website/application. |

* Public transport stations (like commuter trains stations Ⓢ) are automatically shown on the map (i.e. no need to add specific layers).

**Thank you for completing this part of the experiment!**

**Appendix (C):** Counterbalancing Arrangement

| | Task Block selected in desktop session | Task Block selected in smartphone session | Task Block selected in Tablet session |
|---|---|---|---|
| **TP1** | C | B | A |
| **TP2** | B | A | C |
| **TP3** | A | B | C |
| **TP4** | C | B | A |
| **TP5** | A | B | C |
| **TP6** | A | C | B |
| **TP7** | B | C | A |
| **TP8** | A | B | C |
| **TP9** | C | A | B |
| **TP10** | A | C | B |

## **Appendix (D):** General Information

# General Information

Hello! My name is Razan Damlakhi. Thank you very much for coming. Please allow me to briefly explain why you were asked to come in today and what exactly you will be doing.

**WHAT THE STUDY IS ABOUT**:

As part of my MSc research titled: "THE INFLUENCE OF SCREEN SIZE ON SPATIAL TASK PERFORMANCE", you were invited to participate in this research's experiment which investigates the impact of screen size on spatial task performance across three popular computing devices: a desktop computer, a tablet and a smartphone. The main interest here is to gain knowledge and fundamental understanding of the relationship between screen-size and user productivity (i.e. spatial task performance).

**WHAT WE WILL ASK YOU TO DO**:

Due to the changes required in the set-up of the hardware, this experiment will be divided in to /3/ sessions and you will be kindly asked to come to the Lab /3/ times in consecutive days (based on pre-scheduled appointments). For each session, you will be asked to perform a series of short spatial tasks, in first session those tasks will be executed by you on the desktop, then in the second and the third ones will be executed on smartphone and tablet respectively. (Task instructions will be presented to you in a separate sheet). While you are performing the tasks, please talk aloud expressing what you are doing, thinking and feeling.

**YOUR PARTICIPATION WILL BE CONFIDENTIAL:**

You were invited to participate in this experiment because you are an adult over 18 who speaks English.

Your participation in this study is completely voluntary, Please note that this experiment is not meant to test you in any way, but just to learn from you. During the sessions, assistance will be provided when needed.

With your permission, video, audio and eye-movement recordings will be made of your sessions, with the purpose of determining the speed and approach with which you complete some spatial tasks. These recordings will be kept private and will only be utilized for research analysis as the test results will be used as summary statistics. Every participant gets an identification number (TP1, TP2, TP3 and so on) ; in any sort of report to be made public , no reference will be made to names or any other personal information that will make it possible to identify you.

If you have any questions now or at any later stages, please don't hesitate to ask!

**Thank you for taking time to complete this test carefully and accurately.**

**Appendix (E):** The Experiment Protocol

# The Experiment Protocol (for each Participant)

Welcome, your **subject code** is: TP____.

Please follow the next steps and complete the indicated questionnaires consequently:

1- Read **"General information"** sheet.

2- For Session No.1 (Device: ***Desktop computer***). Session date: Feb….. , 2013. Session time:……

- ✓ Fill out the **Pre-test questionnaire**
- ✓ Watch the tutorial/ or the guidelines demo (on the desktop)
- ✓ select a " **Tasks Instructions** " form and read it
- ✓ Calibrate your eyes and place yourself in a proper position.
- ✓ Execute the tasks and think aloud.
- ✓ Fill out the TLX-task load index questionnaire for performing spatial tasks on: ***Desktop computer***
- ✓ Confirm the appointment for the next session

3- For Session No.2 (Device: ***Smartphone***). Session date: Feb….. , 2013. Session time:……

- ✓ Watch the tutorial/ or the guidelines demo (on the desktop)
- ✓ Training on the device (if needed)
- ✓ select a " **Tasks Instructions** " form and read it
- ✓ Calibrate your eyes and place yourself in a proper position.
- ✓ Execute the tasks and think aloud
- ✓ Fill out the TLX-task load index questionnaire for performing spatial tasks on: ***Smartphone***
- ✓ Confirm the appointment for the next session

4- For Session No.3 (Device: ***Tablet***). Session date: Feb….. , 2013. Session time:……

- ✓ Watch the tutorial/ or the guidelines demo (on the desktop)
- ✓ Training on the device (if needed)
- ✓ select a " **Tasks Instructions** " form and read it
- ✓ Calibrate your eyes and place yourself in a proper position.
- ✓ Execute the tasks and think aloud.
- ✓ Fill out the TLX-task load index questionnaire for performing spatial tasks on: ***Tablet***
- ✓ Complete the overall **Post- test questionnaire**
- ✓ Do **the interview** with the research leader

## **Appendix (F):** Pre-Test Questionnaire

# Pre-test questionnaire

Subject Code__________

Kindly answer the next questions on your background and experience.

Please indicate / tick:

1- Which age group do you fit in?

*18-24 *25-30 *31-40 *41-50

2- Gender: -Male -Female

3-Are you color-blind? -Yes -No -I don't know

4- Your educational background (studies field(s)):

--------------------------------------------------------------------------------------------------------------

5- Do you have education and/or work experience in the geo-domain? -Yes -No

6- Do you have practical experience with using touch screen devices, specifically tablets?

- ☐ No
- ☐ Modest
- ☐ Very good experience

7- Do you have practical experience with using touch screen devices, specifically smart phones?

- ☐ No
- ☐ Modest
- ☐ Very good experience

8- How often do you use maps on desktop screens?

- ☐ Every day
- ☐ Couple of times a week
- ☐ Couple of times a month
- ☐ Rarely, incidentally
- ☐ Never

9- How often do you use maps on tablets?

- ☐ Every day
- ☐ Couple of times a week
- ☐ Couple of times a month
- ☐ Rarely, incidentally
- ☐ Never

10- How often do you use maps on smartphones?
- ☐ Every day
- ☐ Couple of times a week
- ☐ Couple of times a month
- ☐ Rarely, incidentally
- ☐ Never

11- Do you have knowledge of Google Maps®?
- ☐ No
- ☐ Poor
- ☐ Modest
- ☐ Very good

12- How often do you use Google maps®?
- ☐ Every day
- ☐ Couple of times a week
- ☐ Couple of times a month
- ☐ Rarely, incidentally
- ☐ Never

13- On which device(s) you have used Google Maps®?
- ☐ Desktop Pc
- ☐ Tablet
- ☐ Smartphone

14- Do you have experience with using Google Maps® for Route Planning?

-Yes -No

15-Do you have experience with using the animated maps in the weather applications (e.g. radar maps)?

-Yes -No

16-If yes, how often do you use such kind of weather applications?
- ☐ Every day
- ☐ Couple of times a week
- ☐ Couple of times a month
- ☐ Rarely, incidentally
- ☐ Never

17-Do you know The Weather Channel application®?

-Yes -No

18- Have you ever been in Berlin (Germany)? -Yes -No

19-How familiar are you with the city of Berlin?

- ☐ Very familiar
- ☐ Average familiarity
- ☐ Not familiar at all

20- Have you ever been in Hamburg (Germany)? -Yes -No

21-How familiar are you with the city of Hamburg?

- ☐ Very familiar
- ☐ Average familiarity
- ☐ Not familiar at all

22-Have you ever been in Frankfurt (Germany)? -Yes -No

23-How familiar are you with the city of Frankfurt?

- ☐ Very familiar
- ☐ Average familiarity
- ☐ Not familiar at all

24-Suppose you want to use digital maps to plan a route for your next trip and you also want to check the expected weather along the route, find locations and get directions. If you were in a room in which there would be a desktop PC, a tablet and a smartphone, which one you would take first to execute such spatial tasks, giving that the three devices are all 'on', i.e. started up?

- desktop computer - tablet - smartphone

Please explain why?

25- What if the three devices are all 'turned off ', which device you would take first to execute such spatial tasks?

- desktop computer - tablet - smartphone

Please explain why?

**Thank you for completing this questionnaire!**

**Appendix (G):** TLX-Task Load Index Questionnaire

## TLX-Task Load Index Questionnaire (after each device tested)

**The Subject code: -----------------------------------** **Date of the test: Feb _____, 2013.**

**The device just tested: ---------------------------**

For the device just tested, please respond to the questions below using the 4-point response scale provided (Please tick the correct answer)

1. **MENTAL DEMAND: How challenging were the tasks you have just executed?**

   Not At All Slightly Moderately Very

   ○ ○ ○ ○

2. **PERFORMANCE: How successful were you in accomplishing what you were asked to do?**

   Not At All Slightly Moderately Very

   ○ ○ ○ ○

3. **EFFORT: How hard did you have to work to accomplish your level of performance?**

   Not At All Slightly Moderately Very

   ○ ○ ○ ○

4. **FRUSTRATION: How insecure, discouraged, irritated, stressed, and annoyed were you in executing the tasks?**

   Not At All Slightly Moderately Very

   ○ ○ ○ ○

5. **Do you have any additional comments about executing such set of spatial tasks on this particular device?**

**Thank you for completing this questionnaire!**

**Appendix (H):** Post-test questionnaire

# Post-test questionnaire

Device Task Load Comparison

Of the three devices tested, please respond to the comparison questions below.

1. **MENTAL DEMAND: Of the devices with which you have executed the tasks, which device was mentally most demanding?**

Desktop ○ Tablet ○ Smartphone ○ no difference/I don't know

2. **EFFORT: Of the devices with which you have executed the tasks, which device required the most efforts?**

Desktop ○ Tablet ○ Smartphone ○ no difference/I don't know ○

3. **FRUSTRATION: Of the devices with which you have executed the tasks, which device was more frustrating?**

Desktop ○ Tablet ○ Smartphone ○ no difference/I don't know ○

4. **PERFORMANCE: Of the devices with which you have executed the tasks, which device provided the best performance?**

Desktop ○ Tablet ○ Smartphone ○ no difference/I don't know ○

The questions below are aimed at comparing the three devices: desktop, tablet and smartphone for the spatial tasks performed with the two applications: Google Maps® and Weather Channel. By ticking an option on the scale, please give an answer to each question for each device.

**1-Does this device enable a *QUICK* (speedy) task performance?**

**Google Maps**

| | | | | |
|---|---|---|---|---|
| **Desktop** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |
| **Tablet** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |
| **Smartphone** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |

**Weather Channel**

| | | | | |
|---|---|---|---|---|
| **Desktop** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |
| **Tablet** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |
| **Smartphone** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |

**2-Does this device enable an *EFFECTIVE* (successful) task performance?**

**Google Maps**

| | | | | |
|---|---|---|---|---|
| **Desktop** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |
| **Tablet** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |
| **Smartphone** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |

**Weather Channel**

| | | | | |
|---|---|---|---|---|
| **Desktop** | ◌ Not At All | ◌ Slightly | ◌ Moderately | ◌ Very |

| | | | | |
|---|---|---|---|---|
| **Tablet** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Smartphone** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |

**3-Does interacting with this device require a lot of *MENTAL EFFORT*?**

| | | | | |
|---|---|---|---|---|
| **Google Maps** Desktop | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Tablet** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Smartphone** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Weather Channel** Desktop | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Tablet** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Smartphone** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |

**4- Was it *EASY* to navigate between menus, pages, on the screen?**

| | | | | |
|---|---|---|---|---|
| **Google Maps** Desktop | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Tablet** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Smartphone** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Weather channel** Desktop | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Tablet** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |
| **Smartphone** | ○ Not At All | ○ Slightly | ○ Moderately | ○ Very |

**5-Has using this display device changed your mind about whether you could do spatial tasks with it?**

**Google Maps**

| | | | | |
|---|---|---|---|---|
| **Desktop** | ◯ Not At All | ◯ Slightly | ◯ Moderately | ◯ Very |
| **Tablet** | ◯ Not At All | ◯ Slightly | ◯ Moderately | ◯ Very |
| **Smartphone** | ◯ Not At All | ◯ Slightly | ◯ Moderately | ◯ Very |

**Weather channel**

| | | | | |
|---|---|---|---|---|
| **Desktop** | ◯ Not At All | ◯ Slightly | ◯ Moderately | ◯ Very |
| **Tablet** | ◯ Not At All | ◯ Slightly | ◯ Moderately | ◯ Very |
| **Smartphone** | ◯ Not At All | ◯ Slightly | ◯ Moderately | ◯ Very |

**Thank you very much for your time and consideration.**

**Your participation is much appreciated.**

**Appendix (I):** The Interview

## The Interview (Open-ended questions)

The Subject code:-------------------------- Date of the test---------------------------------

1 – Please explain how did you enjoy using maps on each device??

2- What were your overall likes and dislikes in performing the tasks (likes first, then dislikes)?

3- This research investigates how users may interact with the maps presented on different sizes of screens (e.g. the amount of zooming and panning you did). Do you feel that there were differences in the types and amounts of interactions while you were executing spatial tasks on each device? If yes, what kind of differences?

4- What is your overall impression of the impact of screen size on task performance? What did you feel the impact was on performing spatial tasks in particular?

5-What was the most difficult thing about planning the route and exploring the weather conditions on Google maps and The Weather Channel application using each of the display devices: desktop, tablet, smartphone? Please comment on which of the three devices was the easiest to read maps on, and why?

6- Now after all the devices are tested, Suppose you want to use a digital map to plan a route for your next trip and you also want to check the expected weather along the route, find locations and get directions. If you were in a room in which there would be a desktop PC, a tablet and a smartphone, which one you would take first to execute such spatial tasks? Please explain why?

- desktop computer - tablet - smartphone

**Thank you very much for your participation!**

**Appendix (J):** TPs' individual characteristics

| TP no. | Gender | Country Of Origin | Background | Previous Experience In Geo-Domain | Knowledge Of Google Maps® | Knowledge Of Weather Channel Application® |
|---|---|---|---|---|---|---|
| 01 | M | Egypt | Chemistry | No | Yes | No |
| 02 | M | Guatemala | System Engineering | Yes | Yes | No |
| 03 | F | Jordan | Geo-matics Engineering | Yes | Yes | Yes |
| 04 | F | India | Information Technology | No | Yes | Yes |
| 05 | F | Mangolia | Geodesy | Yes | Yes | No |
| 06 | M | Egypt | Soil Physics | Yes | Yes | Yes |
| 07 | M | Yemen | Computer Science | No | Yes | No |
| 08 | M | Uganda | Environmental Modelling | Yes | Yes | No |
| 09 | M | Namibia | Geo-informatics | Yes | Yes | No |
| 10 | M | Mexico | Bio-informatics | Yes | Yes | Yes |

## **Appendix (K):** TPs' Experiences

- Per TP: Experience with touch devices

| | | TP1 | TP2 | TP3 | TP4 | TP5 | TP6 | TP7 | TP8 | TP9 | TP10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (Tablet) | No | ✓ | | | | | | ✓ | | | |
| | Modest | | | | | | ✓ | | | ✓ | ✓ |
| | Very Good | | ✓ | ✓ | ✓ | ✓ | | | ✓ | | |
| Smartphone | No | ✓ | | | | | | ✓ | | | |
| | Modest | | | | | | ✓ | | | | ✓ |
| | Very Good | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | |

- Per TP: Using Maps on a device

| | | TP1 | TP2 | TP3 | TP4 | TP5 | TP6 | TP7 | TP8 | TP9 | TP10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Desktop | Daily | | ✓ | ✓ | | | ✓ | | | | ✓ |
| | Weekly | ✓ | | | ✓ | ✓ | | ✓ | ✓ | ✓ | |
| | Monthly | | | | | | | | | | |
| | Rarely | | | | | | | | | | |
| | Never | | | | | | | | | | |
| Tablet | Daily | | | | | | | | | | |
| | Weekly | | | | ✓ | ✓ | | | | | |
| | Monthly | | ✓ | | | | | | | ✓ | |
| | Rarely | ✓ | | ✓ | | | | ✓ | | | |
| | Never | | | | | | ✓ | | ✓ | | |
| Smartphone | Daily | | | | | | | | | | |
| | Weekly | | | | ✓ | | ✓ | | | | ✓ |
| | Monthly | | ✓ | ✓ | | ✓ | | | ✓ | | |
| | Rarely | | | | | | | | | | |
| | Never | ✓ | | | | | | ✓ | | ✓ | |

## - Per TP: How often TP use the applications?

| | | TP1 | TP2 | TP3 | TP4 | TP5 | TP6 | TP7 | TP8 | TP9 | TP10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Google Maps** | Daily | | | | | | | | | | ✓ |
| | Weekly | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| | Monthly | ✓ | | ✓ | | | | | | ✓ | |
| | Rarely | | ✓ | | | | | | | | |
| | Never | | | | | | | | | | |
| | | **TP1** | **TP2** | **TP3** | **TP4** | **TP5** | **TP6** | **TP7** | **TP8** | **TP9** | **TP10** |
| **Weather maps** | Daily | | | | | | | | | | |
| | Weekly | | | | | | ✓ | | ✓ | | |
| | Monthly | | | ✓ | | | | | | | |
| | Rarely | ✓ | ✓ | | | ✓ | | | | | ✓ |
| | Never | | | | ✓ | | | ✓ | | ✓ | |