A USABILITY COMPARISON OF CANVAS, TOPOGRAPHIC, AND STREET BASEMAPS

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A THESIS

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Abstract

Basemaps are a fundamental component of most maps, and may affect the usability of the map. Cartographic guidelines recommend that map authors select a basemap appropriate for the map's intended topic, scale, purpose, context of use and audience. Guidelines for selecting the basemap, however, are not well covered by the usability literature.

Basemap usability research may determine how different basemaps affect the map's usability. In turn, recommendations may be offered to map authors for selecting an optimal basemap type for the map, and the map user(s). In turn, the usability of the map may improve, as well as the users' experience.

This study presents a usability comparison of canvas, topographic and street basemaps. An online survey was designed to evaluate basemap usability. Survey respondents' map reading abilities, and subjective preferences, were compared between each of the three basemap types. Comparisons were made across effectiveness, efficiency and satisfaction usability metrics. In addition to basemap type, the survey examined how map scale, map complexity, map use tasks, and respondents' mapping expertise affected map reading abilities.

Survey results found that basemap type did not significantly affect map usability for search and search-along-route map use tasks. Larger map scales improved respondents' map reading effectiveness, and map reading efficiency was significantly faster for respondents with greater mapping expertise. Map complexity and map use tasks had no significant effect on map reading performance. Basemap preference results show that respondents liked street basemaps the most, and canvas basemaps the least. The relationship between respondents' map reading performance and basemap preferences was also contemplated, with avenues provided for future research.

Table of Contents

List of Figures

List of Tables

Acronyms & Abbreviations

ESRI – Environmental Systems Research Institute

GI – Geographic Information

GIS – Geographic Information System

GLMM – Generalized-Linear Mixed-Effects Model

ICA – International Cartographic Association

ISO – International Organization for Standardization

WFS – Web Feature Service

WMS – Web Map Service

Chapter 1 - Introduction

Maps and Geographic Information Systems (GIS) are increasing in popularity, and usage. Technologies and online capabilities have democratized maps and GIS (Goodchild, 2009; Kraak, 2004), resulting in the proliferation of Web Feature Services (WFS), Web Map Services (WMS) and open source initiatives (Haklay et al., 2008; Harding et al., 2009). Moreover, the global GIS market is expected to continue growing (P&S Market Research, 2016). In turn, prepackaged basemaps will likely become more popular, and more varied.

Basemaps are a fundamental component of most maps. A basemap is a combination of Geographic Information (GI) that forms the background layer of the map. Basemaps provide geographic and contextual reference for the map's thematic data. Many researchers claim that the basemap can affect the map's functional success, and visual appeal (Imhof, 2007; Kraak & Ormeling, 2011; Robinson et al., 1995). In this regard, it is important that map authors choose an appropriate basemap for their map(s).

If an inappropriate basemap is chosen, people may not use the map. According to Foerster et al. (2012), some basemaps are inadequate for supporting specific thematic data. While, mapping systems may provide the necessary tools to create good maps, they typically offer little or no guidance to map authors for doing so (Harding et al., 2009). As a result, map authors often neglect considering what constitutes an appropriate basemap for the users' needs (Harding et al., 2009).

Today, many types of prepackaged basemaps are available, such as: canvas, topographic, street, terrain, imagery, etc. With so many options to choose from, map authors are less inclined to create their own basemaps, and instead borrow basemaps from other maps, individuals and organizations (Muehlenhaus, 2014; Tyner, 2010). Consequently, map authors are faced with an important decision: which basemap is best for my map? Appropriately, there is no definitive 'best' basemap. Instead, cartographic guidelines recommend that map authors select the basemap most appropriate for the map's topic, scale, purpose, context of use and audience (Harding et al., 2009; Kraak & Ormeling, 2011; Robinson et al., 1995). However, guidelines for selecting basemaps are not well covered by the usability literature.

Usability testing may be used to improve a product or service. The goal of usability testing is to uncover problems with design, as well as determine how easy something is for individuals to use (Dumas & Redish, 1999). First and foremost, usability testing aims to improve the users' experience.

International standards for defining usability have been developed by the International Organization for Standardization (ISO) (Bevan, 2001). According to ISO 9241-11, usability is "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (Bevan, 2001). More precisely, "effectiveness measures the accuracy and completeness with which users achieve specified goals; efficiency measures the resources expended in relation to the accuracy and completeness with which users achieve goals; and satisfaction measures the freedom from discomfort, and positive attitudes towards the use of the product" (ISO 9241-11, 1998).

Usability testing can potentially improve users' experiences with maps. The International Cartographic Association (ICA) (2012) states that "map design should always be user oriented (user-centred design), and be based on good knowledge about the elements of usability." By conducting usability testing on maps and GI, maps can be better designed, and users' experiences with maps may improve.

1.1 Gaps in Research

Basemaps are included in the domain of GI usability. Geographic Information usability research focuses on understanding how spatial information may affect users' map reading performance, and overall experience with the map (Brown et al., 2013a; Harding et al., 2009; Hunter et al., 2003). However, basemap usability research is not well covered by the literature.

Comprehensively, the literature presents a great deal of information on the potential uses of different basemap types (Kraak & Ormeling, 2011; Moore & Walz, 2016; Robinson et al., 1995). Several basemap usability studies have compared aerial/satellite imagery basemaps against topographic or generalized basemaps (Dillemuth, 2005; Konečný et al., 2011). However, basemap usability studies comparing rendered basemap types (i.e., street, topographic, canvas, etc.) are not well represented in the cartographic, or usability literature.

This gap in the literature may exist because researchers focus on cartography and geovisualization (Fabrikant et al., 2012; Li & Qin, 2014; Nivala, 2007; Slocum et al., 2001), map complexity (Castner & Eastman, 1985; Fairbairn, 2006; MacEachren, 1982), or GIS and WMS usability (Komarkova et al., 2010; Nivala et al., 2008; Skarlatidou & Haklay, 2006). Furthermore, the contextual and subjective nature of maps and GI (Harley, 1988; Nivala & Sarjakoski, 2003; Wachowicz et al., 2008) may cause researchers to disregard basemap usability testing.

As prepackaged basemaps increase in popularity and usage, it is important to research how different basemap types may affect the map's usability. Basemap usability testing can determine how intuitive and meaningful basemaps are to different users. As a result, recommendations can be offered to map authors for selecting an optimal basemap type for the map, and the map user(s). In turn, map authors can design maps that are more user friendly, and aesthetically appealing.

1.2 Research Questions

This study conducted a usability comparison of canvas (light grey), topographic, and street basemaps. These basemaps were collected from ESRI's ArcGIS Online[1] platform in 2015. Basemap usability was assessed using map reading and user preference evaluations. User testing was involved, and comparisons were made across effectiveness (accuracy), efficiency (response times) and satisfaction (aesthetic preference) usability metrics. This study answers the research question:

How does basemap type affect map usability?

[1] https://www.arcgis.com/home/

Additional variables were considered that could potentially affect basemap usability results. These variables included: map scale, map complexity, map use tasks, and map expertise. On account of these conditions, the research question was supported by the following sub-questions:

i. *How does map scale affect map usability?*
ii. *How does map complexity affect map usability?*
iii. *How does map expertise affect map reading performance?*
iv. *Which basemap types do map users prefer?*
v. *How are map reading performance and basemap preference related?*

1.3 Thesis Structure

Chapter 2 provides a literature review of GI usability, map expertise, basemaps, and basemap usability research. In addition, map scale, map complexity, and map aesthetics literature are explored. Chapter 3 documents the methodology used to design the online survey that measured basemap usability. Results from the survey are presented in Chapter 4, and discussed in Chapter 5. Chapter 6 summarizes the key findings from this study, and provides avenues for future research.

Chapter 2 - Literature Review

Map design and user studies research have grown significantly since the 1950s. During this time, researchers have examined how map and Geographic Information (GI) design can affect map usability. Many studies have proposed theoretical solutions to map authors, and the scientific community.

This chapter reviews past research and literature on map usability, with special attention given to basemaps. The following sections inspect: usability and geographic information, map expertise, basemaps, and basemap usability. This chapter then examines the literature on: map scale, map complexity, and map aesthetics.

2.1 Usability and Geographic Information

Following the Second World War, ‘user interfaces’ were first introduced as computers and large control panels (Spillers, 2007). Around this time, psychologists discovered that fewer buttons, knobs, switches and panels dramatically improved operator performance (Spillers, 2007). Shortly following Robinson’s *The Look of Maps* (1952), researchers began using psychological methodologies to examine how map reading performance was affected by map design (Medyckyj-Scott & Board, 1991). As computer technologies proliferated, GI and computers became integrated (Haklay & Skarlatidou, 2010).

“While Geographic Information Systems (GIS) have been around since the 1960s, only in the late 1980s was attention turned to the ways in which people interact with them” (Haklay & Skarlatidou, 2010, p. 3). Initial GIS usability testing was motivated by increasing competition within the geospatial market (Hunter et al., 2007). Early studies examined GIS usability in the workplace (Davies & Medyckyj-Scott, 1996; Traynor & Williams, 1995). Today, a large body of GIS usability research exists (Haklay & Nivala, 2010; Medyckyj-Scott & Hearnshaw, 1993; Roth et al., 2015); however, there remains a lack of research on the usability of GI (Harding, 2013; Harding et al., 2009; Hunter et al., 2003).

Geographic Information usability research focuses on understanding how spatial information may affect users' map reading performance, and overall experience with the map (Brown et al., 2013a; Harding et al., 2009; Hunter et al., 2003). This research can assess: map features, labels, scale, basemaps, attributes, etc. (Brown et al., 2013b). Specifically, GI usability research can identify design issues that may impact users' understanding of GI (Brown et al., 2013b; Harding, 2013). This research is important because it can allow researchers to differentiate between how users' experience GI, and how they systematically use the map (Brown et al., 2013b; Harding, 2013). In turn, map authors can resolve issues with GI design, and therein improve the usability of the map.

2.2 Map Expertise

Users are the focus of usability studies (Dumas & Redish, 1999). In these studies, researchers often compare observations between novice (less experienced) and expert (more experienced) users (Gerber et al., 1992; Nielsen, 1993; Rubin & Chisnell, 2008). In this study, mapping knowledge and experience is referred to as map expertise.

Many researchers have examined how map reading abilities are affected by map expertise. Several studies have found that map expertise can improve map reading performance (Anderson & Leinhardt, 2002; Konečný et al., 2011; Ooms et al., 2012). For instance, Ooms et al. (2012) found that expert map users had greater map reading efficiency than novice map users. They presumed that additional background knowledge and experience were the cause of this increase in map reading efficiency. Similar conjectures have been made about chess players, where experienced players typically perform better than inexperienced players as a result of their accrued knowledge and experience (Gobet & Simon, 1998).

Comparatively, other user studies have found that map expertise does not improve map reading performance (Deeb et al., 2014; Fabrikant, 2001; Gilhooly et al., 1988). For instance, Gilhooly et al. (1988) found that map expertise had no significant effect on map users' ability to read planimetric maps (i.e., maps showing only the x and y locations of features across horizontal distances). According to Kulhavy and Stock (1996), map expertise had no effect on how map users process basic map information.

Comprehensively, researchers recommend that map authors consider the map users' backgrounds when designing the map (Foerster et al., 2012; Harding et al., 2009; MacEachren, 1995). If a map is intended for inexperienced users, its design should be simpler than a map intended for experienced users (Forrest, 1999). For instance, a geological map often requires some level of field-related or mapping knowledge for effective use (Kimerling et al., 2012; MacEachren, 1995). In this sense, a geological map may not be appropriate for all users.

It is important that researchers investigate the appropriateness of maps and GI for different user groups so that map authors may design more 'user friendly' maps that accommodate different map purposes, and users' needs (Brown et al., 2013b; Harding et al., 2009; Ooms et al., 2012). Furthermore, assessing users' map expertise within user studies is important for determining if results fairly represent typical users found outside of the experimental framework.

2.3 Basemaps

A basemap is a combination of GI that forms the background layer of the map. Basemaps provide geographic and contextual reference for the map's thematic data. Using various combinations of GI, visual variables and aesthetics, different basemaps can be created.

Many types of prepackaged basemaps are now available, such as: canvas, topographic, street, terrain, imagery, etc. Map authors may create their own basemaps, or use ones borrowed from other maps, individuals and organizations (Frank, 1992; Tyner, 2010). Today, map authors typically use prepackaged basemaps created by others, rather than create their own (Muehlenhaus, 2014).

Basemaps can be grouped into two categories: aerial/satellite imagery (raster-based), and rendered (vector-based) – although hybrid basemaps (aerial/satellite imagery with overlying rendered data) also exist (Kimerling et al., 2012; Moore & Walz, 2016). In the literature, rendered basemaps may also be referred to as topographic basemaps (Kraak & Ormeling, 2011; Moore & Walz, 2016). To avoid confusion with topographic basemap styles, this study uses the term rendered basemaps to describe vector-based basemaps.

Aerial and satellite imagery basemaps are created using data collected via cameras and sensors on aircraft or remote-sensing satellites (Kimerling et al., 2012; Longley et al., 2005). Using these data-collection techniques, aerial/satellite imagery basemaps provide "an unbiased picture of what is on the ground, serving as a historical record of change on our planet" (DigitalGlobe, 2016). The temporal aspects of aerial/satellite imagery basemaps are particularly useful for showing land use and land cover changes, natural disaster effects, and property-related information (Kimerling et al., 2012; Kraak & Ormeling, 2011). However, aerial/satellite imagery basemaps' inability to filter out unnecessary data may inhibit map users' map reading abilities (Peterson, 2009; Roth, 2009). For instance, it can be difficult to display labels and thematic data over aerial/satellite imagery in a clear and legible way (Imhof, 2007; Peterson, 2009). Aside from this concern, aerial/satellite imagery can be a particularly valuable basemap layer for the map.

Rendered basemaps are created using digitization processes (typically of aerial/satellite imagery), and are composed of vector points, lines and polygons contained in a geodatabase (Longley et al., 2005). These basemaps can allow for the visualization of infrastructure, political borders, and other cultural features (Kimerling et al., 2012; Kraak & Ormeling, 2011). Rendered basemaps also allow map authors to emphasize and/or generalize GI according to the map's or users' needs (Kraak & Ormeling, 2011). For instance, map authors can simplify, smooth, merge, resize and displace GI that is in vector format (McMaster & Shea, 1992). As a result, map authors can prioritize or suppress GI as necessary, and dictate the visual hierarchy of the map (MacEachren, 1995; Peterson, 2009). In turn, rendered basemaps are subjective, and representative of the map authors' point of view (Imhof, 2007; Kraak & Ormeling, 2011; Wood, 1993).

Different rendered basemaps serve different artistic and functional roles. Street basemaps promote transportation networks by exaggerating the size, contrast and labels of transport utilities (Moore & Walz, 2016). These characteristics make street basemaps ideal for communicating transport-related information. Topographic basemaps emphasize natural features (i.e., mountains, lakes and vegetation) and may use contour lines to show changes in elevation (Kimerling et al., 2012; Kraak & Ormeling, 2011). As a result, topographic basemaps are useful for visualizing and navigating outdoor terrain.

Canvas basemaps generally show less GI content (i.e., fewer basemap features and visual variables), and typically use a monochromatic colour scheme (commonly grey) (Akella & Yule, 2011). In turn, canvas basemaps can be an optimal choice when map authors want to reduce visual distractions, and highlight thematic data (Akella & Field, 2011a; Akella & Field, 2011b).

Overall, many types of basemaps exist, each with varying artistic and functional capabilities. The literature shows that map users generally prefer rendered basemaps over aerial/satellite imagery basemaps (Dillemuth, 2005; Longley et al., 2005; Skarlatidou & Haklay, 2006). As more prepackaged basemaps become available, the number of different basemap types is expected to increase. By understanding the advantages and disadvantages associated with different basemap types, map authors can select the basemap that is most appropriate for the map's purpose, and the users' needs.

2.4 Basemap Usability

Many researchers claim that the basemap can affect the map's functional success, and visual appeal (Imhof, 2007; Kraak & Ormeling, 2011; Robinson et al., 1995). In this regard, it is important that map authors choose an appropriate basemap for their map(s).

According to Harding (2013, p. 940), "evaluating the usability of a product is in large part dependent on who the users are, and what they are using the product for." In this regard, the usability of the basemap is specific to the users and contexts in which it may be used. The cartographic design of the basemap is also important for attracting users, and successfully communicating spatial information (Brewer, 2004; Karssen, 1980; Robinson et al., 1995). This section reviews basemap usability through an exploration of the users, contexts of use, and cartography of basemaps. Previous basemap usability research is examined, and relations between performance and preference are also discussed.

2.4.1 Users, Context, and Cartography

Users consider a product or service ‘usable’ when it is intuitive, informative and meaningful (Dumas & Redish, 1999). The literature recommends that map authors have the intended user(s) in mind when designing the map (Foerster et al., 2012; Harding et al., 2009; Peterson, 2009). The backgrounds and map expertise of modern-day map users, however, are widely diverse (Konečný et al., 2011; Lloyd & Bunch, 2003; Ooms et al., 2016). As a result, map authors may only have basic knowledge of the potential users (Brown et al., 2013a). In turn, basemaps are rarely designed for specific map users (van Elzakker, 2005). For this reason, basemap usability research may be an appropriate means of understanding map users’ needs when it comes to basemaps.

Context is considered an important aspect of usability studies (Bevan, 2001; Maguire, 2001; Thomas & Bevan, 1996). Dey (2001, p. 5) defines context as “any information that can be used to characterise the situation of an entity.” According to Thomas and Bevan (1996, p. 82), “for a product to be usable by its intended users, and to be evaluated with meaningful results, the contexts in which that product is used need to be carefully considered, and well documented.” Fundamentally, it is important to integrate contextual design into applications so that the appropriate information is provided at the appropriate time for users (Dey, 2001).

Regarding maps, context may describe the situation of GI on the map, or the situation in which the map is used in the real world. The literature shows that context is important for the presentation of GI (Foerster et al., 2012; Gilmartin, 1981; Lautenschütz, 2012). For instance, Gilmartin (1981) found that map users’ perceptions of thematic data could be influenced by the visual context and characteristics of surrounding information. Specifically, map users’ perceptions of graduated symbol sizes were influenced by surrounding symbols, and internal borders were shown to reduce the illusion of size differences (Gilmartin, 1981). Similarly, Lautenschütz (2012) found that map users’ accuracy significantly increased when thematic data was supported by a geographic, rather than abstract, context. Lautenschütz (2012) also noted that map users’ confidence in the data improved when a geographic basemap was provided.

Designing basemaps for contextual use (i.e., to be used for various purposes, and supporting different thematic data) has been done before. For instance, Wesson and Glynn (2013) used colour science to create a 'bespoke backdrop style'. This contextual basemap design uses subtle colours to maintain good visual hierarchy, while still allowing thematic data to stand out. As a result, more colour options may be used for the thematic data, as colours on the map no longer compete with one another for attention.

Context is may also address the environment or situation in which the map may be used (Jokinen, 2007; Nivala & Sarjakoski, 2003). According to Nivala and Sarjakoski (2003, p. 15), contextual design is necessary for ensuring that "the user has the right type of map, at a suitable scale, and with the symbology adapted for the specific usage situation." As a result, the literature recommends that map authors consider the map's intended context of use (Dillemuth et al., 2007; Harding et al., 2009; Nivala & Sarjakoski, 2003).

Cartography is also important for basemap usability. Generally speaking, cartography is the art and science of designing maps. The cartographic design of the basemap may affect the map's usability, and the users' experience (Dillemuth, 2005; Kent, 2005; Phillips & Noyes, 1982). According to Foerster et al. (2012, p. 101), "topological consistency between the basemap and the thematic content helps the user to link the situation on the map to the real-world situation, and thereby improves map communication."

The literature recommends that map authors select a basemap with cartography appropriate for the map's topic, purpose, context of use, and audience (Harding et al., 2009; Kraak & Ormeling, 2011; Robinson et al., 1995). An inappropriate cartographic design may cause the map user to make inconvenient, costly or even dangerous mistakes (Phillips, 1979). For instance, intensive and bright colours used improperly may distract map users enough that critical information goes unnoticed (Imhof, 2007). In this regard, the cartographic design of the basemap should be intuitive, and appeal to users' aesthetic preferences.

2.4.2 Previous Research

Basemap usability studies often compare two or more basemap types to determine which type may be more appropriate for certain users, or contexts. For instance, Konečný et al. (2011) compared the usability of topographic (rendered) and orthophoto (satellite imagery) basemaps for crisis management situations. They found that map users had more difficulty using the orthophoto basemaps, and presumed this was due to an excessive amount of information being shown to the map user(s). They also discovered that map users took significantly longer to complete tasks when using the orthophoto basemaps. In regard to the map users' expertise, task completion times were faster for users with greater map expertise, than those with less map expertise. Based on these findings, Konečný et al. (2011) concluded that topographic (rendered) basemaps were more appropriate than orthophoto (satellite imagery) basemaps for crisis management situations.

Dillemuth (2005) compared the usability of generalized (rendered) and aerial imagery basemaps for field-based navigation tasks on a mobile device. She found that map users could identify GI easier using the generalized basemap, and performed better as a result. Map users also preferred the generalized basemap over the aerial imagery basemap. In addition, experienced map users completed tasks significantly faster than inexperienced map users. As a result, Dillemuth (2005) concluded that the generalized (rendered) basemap was more appropriate than the aerial imagery basemap for field-based navigation tasks on a mobile device because it was easier to use, and more appealing. Similar results were observed by Dong et al. (2014), who found that enhanced (processed) satellite imagery basemaps were easier to interpret than unmodified satellite imagery basemaps.

Phillips and Noyes (1982) compared the usability of different topographic (rendered) basemaps with a focus on how visual clutter affected map users' map reading performance. Five topographic map designs with varying amounts of features, lines and points were compared. Their results determined that reducing visual clutter improved map users' map reading performance. They also noted that map expertise significantly improved map reading performance.

Although no user testing was involved, O'Beirne (2016) conducted a cartography comparison of Google Maps and Apple Maps using side-by-side visual comparisons. Both basemap styles were compared across 54 map scales, and 3 different cities (New York, San Francisco and London). He observed that Google Maps tended to show more road labels and highway shields, whereas Apple Maps tended to show more city/town labels, and points of interest. Based on his observations, O'Beirne (2016) concluded that Google Maps' designers likely prioritize transport-related content, while Apple Maps' designers prioritize landmark and attraction-related content. However, recent redesign efforts by Google Maps appear to have put more cartographic emphasis on 'locations of interest'.

While O'Beirne's (2016) study did not evaluate the usability of Google Maps and Apple Maps through a user studies approach, his comparison of basemap cartography is still valuable for basemap usability research. For instance, basemap cartography and context evaluations such as this could be useful for map authors considering using either Google Maps or Apple Maps Application Programming Interfaces (APIs) for their own Web Map Service (WMS) or GIS applications. By understanding the cartographic tendencies of other prepackaged basemap types, map authors can determine which basemap type may be more appropriate for the map's, and users' needs.

2.4.3 Performance and Preference

Map usability is often assessed from either a functional or artistic point of view (MacEachren, 1995; Phillips & Noyes, 1982; Wood, 1993). A functional perspective critiques maps based on how well they do their jobs, and allow the map user(s) – whether novice or expert – to use the map efficiently, and without error (Forrest, 1999; Phillips & Noyes, 1982). An artistic perspective critiques maps based on how pleasing they are to look at, and satisfying to use (Karssen, 1980; Kent, 2005; Wood, 1993). Both perspectives, however, suggest that the height of the map's usability is when it contains as much information as possible, without becoming illegible, unattractive or unusable (Phillips & Noyes, 1982). In this regard, an optimal map is one that enables the user(s) to use the map with ease, while also appealing to the map users' artistic and aesthetic preferences (MacEachren, 1995; Robinson et al., 1995; Wood, 1993).

Many map authors seek a balance between functionality and artistic appeal when designing the map (Kent, 2005). The literature shows that user performance and user preference are related (Aykin & Aykin, 1991; Kessell & Tversky, 2011; Nielsen & Levy, 1994). Strong correlations between users' perceptions of usability and usability itself have also been observed (Sonderegger & Sauer, 2010; Tuch et al., 2012; Tractinsky et al., 2000). For instance, Lee and Koubek (2010) found that users' perceptions of usability endured even following the actual use of a system. In this sense, a basemap that is easier to use may be more preferable to users, and vice versa.

Ortag (2009) investigated how aesthetics could affect users' perceptions of map usability. He found that map users tend to evaluate usability based on their perceptions of beauty and artistic design, more so than perceived functionality. Based on Ortag's (2009) findings, it can be assumed that if a basemap is perceived as unappealing or difficult to use, its users will more than likely find the basemap (and map) hard to use.

Map users may develop preferences for a map style through being exposed to similar content (Kong et al., 2015; Šavrič et al., 2015). For instance, Kong et al. (2015, p. 289) found that map users "liked basemaps with distinguishable colours, or ones familiar from their previous web map experience, such as the Google Map style." Psychological studies also show that subjective preferences are closely related to familiarity (Bornstein, 1989). In this regard, map users' subjective preferences for different basemap types may stem from their previous exposure to and usage of specific basemap types.

ESRI's most popular basemaps include: aerial/satellite imagery, streets, topographic, and canvas basemaps (ESRI, n.d.). Figure 2-1 shows the most viewed basemaps found on ArcGIS Online[2] (as on 27/06/2016). At the time of assessment, "Streets" was their most viewed basemap type, followed by "Topographic" and "Imagery with Labels". However, a popular basemap is not necessarily the most usable (Hu et al., 2015; Hunter et al., 2007). By investigating how map users' map reading performance is related to their basemap preferences, map authors may better understand the relationship between basemap usability, and basemap preference. In turn, map authors may be able to determine an optimal basemap type for the map's purpose, as well as the users' needs.

[2] http://www.arcgis.com/home/gallery.html

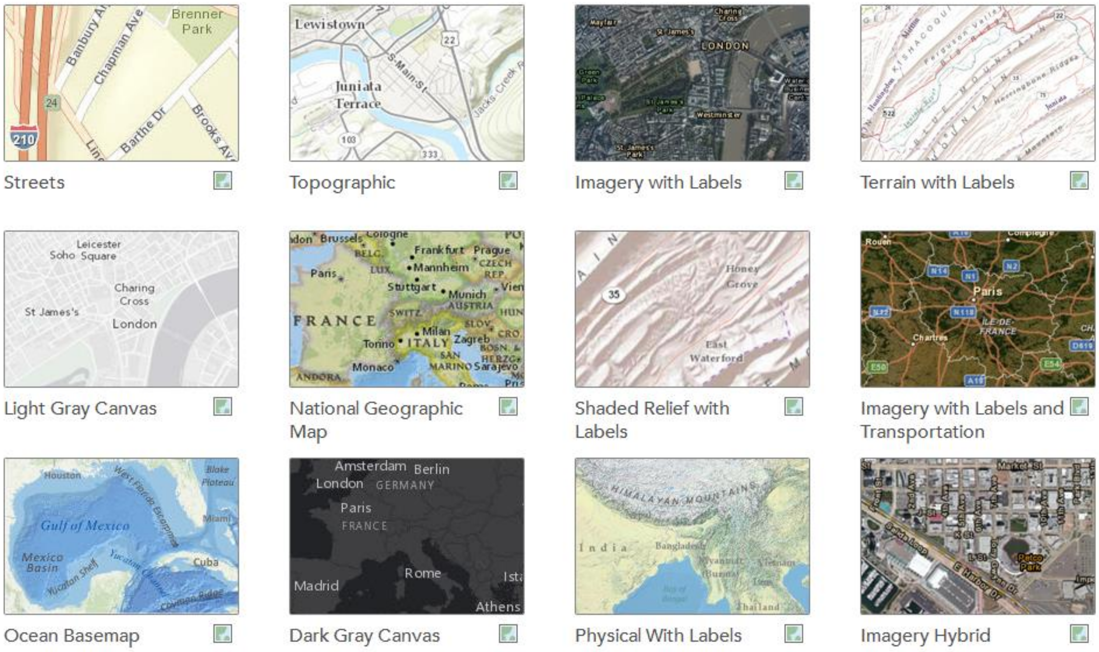

Figure 2-1: ESRI's most viewed basemaps from ArcGIS Online (as on 27/06/2016).

2.5 Map Scale

All maps of the real world are abstractions, and in turn, have a map scale (Robinson et al., 1995). A map's scale defines the relationship between what is seen on the map, with its actual size in the real world (Kraak & Ormeling, 2011; Krygier & Wood, 2011). The usefulness of the map's detail, symbolization and map projection may all be affected as the scale of the map changes (Anderson & Leinhardt, 2002; Fabrikant, 2001; Goodchild & Quattrochi, 1997). The map's scale can also affect how GI is used, and understood on the map (Eastman, 1981; Kraak & Ormeling, 2011; MacEachren, 1995). In this regard, if the map's scale is inappropriate for the map users' needs, the map may be difficult to use.

Map scales are often referred to as either: large scale, or small scale (Dillemuth et al., 2007; Krygier & Wood, 2011; Monmonier, 2014). Large scale maps show less geographic area and more detail, while small scale maps show more geographic area and less detail (Dempsey, 2011; Krygier & Wood, 2011; Monmonier & Schnell, 1988). The literature shows that neither map scale (large or small) is inherently more usable than the other (Goodchild & Quattrochi, 1997; Joao, 1998; Kimerling et al., 2012); however, the map's scale may significantly affect the map users' experience with the map (Dillemuth et al., 2007; Fabrikant, 2001; McMaster & Shea, 1992).

Large and small map scales serve different purposes, and have different advantages and disadvantages. For instance, large scale maps can provide map users with a highly-detailed context for a small geographic area (i.e., show more surrounding geographic features relevant to the map users' needs) (Kraak & Ormeling, 2011; Monmonier & Schnell, 1988). Comparatively, small scale maps can show GI across a national or global scale, which map users may otherwise not be able to comprehend (Kraak & Ormeling, 2011; Monmonier & Schnell, 1988). However, depending on how the map author utilizes geographic space, both large and small scale maps can show too much or too little detail, as well as too many or too few features for the map users' needs (MacEachren, 1995; McMaster & Shea, 1992). In turn, map users may feel uncertain about the accuracy of the map (Dempsey, 2011; Forrest, 1999).

Generalization is a potential method used to transform GI to the map's scale for optimal usability (Agrawala & Stolte, 2001; Goodchild & Quattrochi, 1997; McMaster & Shea, 1992). All maps are generalized to some extent (Joao, 1998; Robinson et al., 1995; Roth et al., 2011). Generalization is typically used to counteract or eliminate the undesirable consequences of congestion, coalescence, conflict, complication, inconsistency and/or imperceptibility of GI, as a result of the map's scale (McMaster & Shea, 1992). For instance, Joao (1998, p. 3) claims "when the scale of a map is decreased, there is less physical space in which to represent the geographic features of a region. As the process continues, the features will need to be exaggerated in size in order to be distinguishable at a smaller scale. As geographical features 'fight' for representation in the reduced map space, some features will need to be eliminated, and those remaining may be further simplified, smoothed, displaced, aggregated or enhanced". Generalization allows map authors to reduce visual clutter, emphasize important features, and dictate the visual hierarchy of the map (MacEachren, 1995; McMaster & Shea, 1992; Roth et al., 2011).

Overall, the level of detail, viewing extent, visual variables and level of generalization associated with the map's scale may all affect the usability of the map (Goodchild & Quattrochi, 1997; McMaster & Shea, 1992; Roth et al., 2011). Generally speaking, the map's scale can affect the usability of the basemap because changes in the map's scales may affect the level of detail, or level of generalization, of the basemap. By understanding how a map's scale may impact map usability, map authors can design maps using a scale that visualizes GI in an appropriate manner relevant to the map users' needs.

2.6 Map Complexity

In part due to the proliferation of GI and Web Feature Services (WFS) in recent decades, map authors can overload maps with too much information, potentially making them too complex and difficult to use (Ciolkosz-Styk & Styk, 2013; Fabrikant, 2001). As a result, map complexity can affect the map's usability. This issue has led researchers to investigate how map users' perceive and experience 'complexity' within maps (Ciolkosz-Styk & Styk, 2013; Fairbairn, 2006).

Map complexity can define how complicated, cluttered or 'busy' the map is. According to MacEachren (1982, p. 31), "map complexity is related to both the nature of the distributions mapped, and the symbolization used in representing those distributions." In this sense, map complexity can be used to describe the organisation and/or design of GI on the map. Map complexity may also relate to the nature of map use tasks, and map users' expended effort processing GI (Castner & Eastman, 1985; Fairbairn, 2006). This form of map complexity is defined as functional or intellectual complexity, and relates to the map, the map user, and the environment in which the map is used (Castner & Eastman, 1985; MacEachren, 1982).

Comprehensively, the literature recognizes two forms of map complexity: visual, and intellectual (Castner & Eastman, 1985; Fairbairn, 2006; MacEachren, 1982). Visual map complexity relates to the cartographic design of the map, and is directly influenced by the map author (MacEachren, 1982). Intellectual map complexity relates to the map user's mental understanding of the map or GI, and is influenced by the user's knowledge, personal experience and cognitive abilities (Castner & Eastman, 1985; MacEachren, 1982). Both visual and intellectual complexities exist within every map (Castner & Eastman, 1985; Fairbairn, 2006; MacEachren, 1982).

Many researchers agree that individuals' perceptions of complexity are context-dependent, or subjective (Gell-Mann, 1995; MacEachren, 1982; Phillips & Noyes, 1982). Specifically, studies contend that map users' familiarity or experience with the map (or GI) can affect how map complexity is perceived (Edler et al., 2014; Fairbairn, 2006). Aesthetics may also affect users' perceptions of complexity (Keates, 1996; Hekkert &

Wieringen, 1990). These studies imply that map users' perceptions of map complexity are psychological, more than the result of visual variables and map design principles alone. However, it is easier for researchers to evaluate visual map complexity rather than intellectual map complexity, as cartographic complexity may be measured quantitatively (Fairbairn, 2006).

2.6.1 Previous Research

Map complexity research first peaked during the 1970s and 1980s when researchers began evaluating map and GI complexity using psychological methods (Montello, 2002). Early map complexity studies examined the geometric composition of maps – particularly, the number of edges, polygons, vertices and classes within the data – and primarily focused on choropleth and thematic mapping (MacEachren, 1982; Monmonier, 1974). Soon after, researchers began investigating how map complexity affected map users' map reading abilities using eye-tracking technologies (Antes et al., 1985; Castner & Eastman, 1985; Steinke, 1975). Over time, the map complexity body of research grew to include map users' perceptions of visual variables, different map designs and interactive GI/GIS, as well as how those perceptions varied between different map user profiles (Ciolkosz-Styk & Styk, 2013; DuBois & Battersby, 2012; Lorenz et al., 2013).

A crucial element of all map complexity studies is determining how to define and measure map complexity (Fairbairn, 2006; Harrie & Stigmar, 2010). Previous studies have measured map complexity by the number of map features, feature classes, graphical density, or use of colour (Fairbairn, 2006; MacEachren, 1982; Stigmar & Harrie, 2011; Touya et al., 2015). When assessing usability, maps are often compared in terms of map complexity (i.e., map A is more complex than map B) rather than assigned a definitive map complexity value (i.e., map A is *n* complex and B is *n* complex) (Fairbairn, 2006). Evaluating map complexity in this way allows researchers to compensate for the subjectiveness of map users' perceptions of complexity (Fairbairn, 2006).

The literature shows that different levels of map complexity can affect map users' map reading abilities (Castner & Eastman, 1985; Edler et al., 2014; MacEachren, 1982). Additionally, varying methodologies for measuring map complexity can affect research outcomes (Fairbairn, 2006; Stigmar & Harrie, 2011). Several studies contend that greater map complexity is useful, as it may provide more information to the map user(s) (Castner & Eastman, 1985; MacEachren, 1982). However, greater map complexity may also make using the map more difficult (Castner & Eastman, 1985; Monmonier, 1974; Phillips & Noyes, 1982). For instance, Castner and Eastman (1985) found that map users' eye fixations were longer for more complex maps than less complex ones, suggesting that map users may require more time to interpret complex information. Additionally, Phillips and Noyes (1982) found that visual clutter inhibited map users' map reading performance. As a result, they concluded that more complex maps and GI criteria may require greater mental processing efforts by the map user(s).

It is generally agreed that while increases in map complexity may be potentially useful, at a certain extent, overwhelming complexity may cause the map to become unusable (Castner & Eastman, 1985; Edler et al., 2014; MacEachren, 1982). For instance, MacEachren (1982) found that as the number of categorical classes within the map increased, map users' understanding of the mapped information also increased. However, he also observed that when the map became too complex for the map user, the map's ability to communicate information rapidly declined. After observing this effect, studies have concluded that a curvilinear relationship exists between map complexity and map usability, where map communication may improve with complexity, but only up to a certain extent specific to the map user(s) (Edler et al., 2014; MacEachren, 1982).

Map complexity is also shown to affect user interest (Keates, 1996; MacEachren, 1982; Yarnal & Coulson, 2013). As observed by MacEachren (1982), when map complexity increased, visual appeal and map user interest also increased. Other studies have also suggested that user interest may increase with map complexity (Edler et al., 2014; Keates, 1996; Yarnal & Coulson, 2013). According to Tufte (1989), people may find complex images rich and interesting, while less complex images ambiguous and unexciting. This notion was seen by Keates (1996), who observed that Swiss topographic maps – more graphically complex than other topographic maps – were generally favoured by map users despite their complexity. A curvilinear relationship between complexity and user interest – similar to that proposed by MacEachren (1982) – has also been observed in the art literature (Berlyne, 1970; Hekkert & Wieringen, 1990).

2.7 Map Aesthetics

Aesthetics play an important role in cartographic design, and map usability. Aesthetics can make the map more appealing, and easier to use (Brewer, 2004; Kent, 2005; Peterson, 2009). According to Tuch et al. (2012, p. 1,596), "in order to create a good user experience, it is important to understand the relation between aesthetics and usability." In turn, aesthetics are important for basemap usability.

Merriam-Webster Online (n.d.) defines 'aesthetic' as: artistic; pleasing in appearance; and of, or relating to beauty. Like all visual products, a map uses aesthetics to attract users, and appeal to their interests (Imhof, 2007; Karssen, 1980; Wood, 1993). Map aesthetics may describe the design of map elements (e.g., colour, line styles, relief visualization, font types, etc.), as well as the harmony of these aesthetic properties on the map (Karssen, 1980; Ortag, 2009; Peterson, 2009).

The literature shows that aesthetics can affect the map's functionality (Imhof, 2007; Kent, 2005; Skarlatidou et al., 2010). For instance, map aesthetics can improve the communication of GI, and direct map user(s) to important information on the map (Brewer, 2004; Krygier & Wood, 2011; Skarlatidou & Haklay, 2006). Using aesthetics properly, a good visual hierarchy can be established, potentially making the map pleasant to view, and easier to use (Kraak & Ormeling, 2011; Peterson, 2009; Skarlatidou et al., 2010).

Colour is regarded as one of the most important aesthetic properties on the map (Brewer, 2004; Fabrikant et al., 2012; Peterson, 2009). Colour has psychological and subjective ties to people, cultures and communities (Karssen, 1980; Ortag, 2009), and has been shown to affect map users' map preferences (Buckingham & Harrower, 2007; Kong et al., 2015; Mendonça & Delazari, 2014). Maps with semantically correct colours (i.e., greens for vegetation and blues for water) are also typically more appealing to map users (Fabrikant et al., 2012; Peterson, 2009). However, maps and aesthetic properties are subjective to individuals, meaning that different map users may prefer different map designs (Karssen, 1980; Kent, 2005).

Imhof (2007, p. 72) promotes four guidelines to map authors for effective colour use on the map. First, intensive colours can cause negative effects when used improperly. Second, light and bright colours adjacent to one another are generally perceived as unpleasant by users. Third, background or base colours are generally more effective when muted, or given a neutral colour such as grey. And fourth, the unity of the map, or image, is best maintained when colours are repeatedly used throughout the map. Following these recommendations, map authors may use colour to design maps (and basemaps) that are easier to use, and more aesthetically appealing to the map user(s).

By and large, aesthetics can affect users' impressions and experiences with the map. The literature recommends that map authors promote and preserve traditional artistry, and aesthetic beauty within maps (Imhof, 2007; Karssen, 1980; Kent, 2005). For these reasons, it is important that researchers examine map users' map (and basemap) preferences. In turn, map authors may better understand which aesthetic properties are most preferred by map users, and therein design maps that enhance the users' experience with the map.

Chapter Summary

Basemap usability research focuses on understanding how basemaps may affect map users' map reading performance, and overall experience with the map. Users are the focus of usability studies, and map expertise is often compared in map usability research. This literature review contends that basemap usability testing requires consideration of the map users, contexts of use, and cartographic design of basemaps. In addition, map scale, map complexity, and map aesthetics may all affect the map's usability, and should be considered by map authors when designing the map.

As stated by Moore and Walz (2016), "picking a good basemap is important, but it doesn't have to be hard." Through basemap usability research, map authors can better understand how basemaps allow the map to succeed both functionally, and aesthetically. In consequence, map authors can use this information to consider what constitutes an appropriate basemap for the map's purpose, and the map users' needs.

Chapter 3 - Methodology

An online survey was created to investigate and compare the usability of canvas, topographic, and street basemaps. Basemap usability was assessed by comparing respondents' map reading performance, and subjective preferences, for each of the three basemap types. Comparisons were made across effectiveness (accuracy), efficiency (response time), and satisfaction (basemap preference) usability metrics. In addition to basemap type, the survey examined how map scale, map complexity, map use tasks, and map expertise affected respondents' map reading performance.

Canvas, topographic and street basemap types were chosen because of their popularity on ArcGIS Online (ESRI, n.d.), and because usability comparisons of these basemap types are not well represented in the usability literature. All basemaps evaluated in this study were acquired from ESRI's ArcGIS Online basemap gallery[3]. Aerial/satellite imagery basemaps were not examined in this study because they visualize Geographic Information (GI) differently (raster-based), and are excessively complex in comparison to rendered basemap types (Kimerling et al., 2012; Kraak & Ormeling, 2011; Peterson, 2009). Furthermore, several studies have already conducted usability comparisons of aerial/satellite imagery basemaps against topographic or generalized basemaps (Dillemuth, 2005; Konečný et al., 2011).

This chapter presents the methodological design of the online survey. The survey's design was derived from a combination of practices and methodologies found in the usability literature. The survey was composed of four sections: 1) demographics, 2) map expertise, 3) map reading, and 4) basemap preference. Each section is examined throughout this chapter, along with discussions of the analysis methods, recruitment and methodological assumptions.

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3 https://www.arcgis.com/home/gallery.html

3.1 Online Survey

The online survey was created and administered using Qualtrics[4]. Qualtrics is a web-based research application used for generating online surveys, and conducting academic research (Carr, 2013). An online survey was used because they are inexpensive, and can return more responses than usability testing methods (Haklay & Zafiri, 2008). Specifically, Qualtrics was chosen because it could record respondents' accuracy scores (correct/incorrect) and response times.

Demographic and map expertise information was collected using multiple choice survey questions. Map reading and basemap preference information was collected by showing maps to respondents, and asking them answer a survey question (multiple choice) about the map. Map reading performance was assessed by comparing respondents' accuracy scores and response times between survey questions (maps). Basemap preferences were assessed by comparing respondents' preference ratings (Likert scale) between basemaps.

The maps (and basemaps) used in the survey were static (non-interactive), and 600 x 400 pixels in size. Legends were created for maps in the map reading section only. Maps were presented on different pages of the survey to ensure that response times, and subjective preferences, were measured independently. Maps, legends, survey questions and navigation widgets (next and previous buttons) were positioned to fit within monitor/screen sizes of at least 14 inches. As a result, respondents did not have to navigate (scroll) around survey pages to view content, which could potentially affect response time measurements. Furthermore, the maps were ordered so that basemap types and geographic locations did not repeat.

Overall, the online survey contained 56 survey questions, 18 maps (map reading), and 27 basemaps (basemap preference). The survey was designed to take no longer than 20 minutes to complete (determined from pilot testing). Ethics approval for this study was granted by the University of Canterbury. Each section of the survey is detailed in the following chapter sections.

[4] www.qualtrics.com

3.2 Demographics

The demographics section of the survey asked respondents about their age, gender, education, and geographic location. Respondents' identities were anonymous. The purpose of the demographic questions was to provide contextual information for the survey results, and assess the survey audience for over or under representation. This information could potentially affect the interpretation of results. The demographic survey questions are included in Appendix A.

3.3 Map Expertise

The map expertise section of the survey quantitatively measured respondents' mapping knowledge, and experience. Multiple-choice survey questions were used. Based on respondents' answers, map expertise scores were calculated, and respondents were categorized into one of three map expertise groups: beginner, competent, or proficient. Establishing these groups allowed for respondents' map reading performance and basemap preference results to be compared between different map expertise groups.

While many usability studies categorize users by expertise (Anderson & Leinhardt, 2002; Deeb et al., 2014; Ooms et al., 2012), few methodologies are provided for quantitatively measuring spatial expertise (Huynh & Sharpe, 2013). Studies often assign participants to either novice or expert user groups based on specific qualifications, or enrolment in educational curricula (e.g., Anderson & Leinhardt, 2002; Ooms et al., 2014). Huynh and Sharpe (2013) proposed an assessment instrument for measuring geospatial expertise by identifying core geospatial concepts, and creating test questions to measure those concepts. Weightings were placed on test questions, allowing them to quantifiably estimate an individual's geospatial expertise. This study's methodology for measuring map expertise was based on the expertise assessment instrument put forward by Huynh and Sharpe (2013).

Seven questions were created to measure map expertise. Question 1 asked respondents to rate their own level of map expertise. Questions 2-7 examined map usage in respondents' working and daily lives, as well as map creation and map use training experience. The map expertise survey questions are included in Appendix B.

Respondents' map expertise was measured as follows. Weightings were assigned to the multiple-choice answers for map expertise questions 1 through 6. Low map use experience answers were weighted 1 point, moderate map use experience answers 2 points, and high map use experience answers 3 points. Question 7 asked respondents which types of maps they had used within the past month, and instructions were to select all answers that applied. Nine answer options were available. Eight options were weighted 0.5 points, while the ninth option, "None", was weighted 0 points. For each answer option the respondent selected, the score for that question increased, up to a maximum of 4 points.

Respondents' points for each map expertise question were summed to produce a total score (Table 3-1). This score was averaged, and then rounded to the nearest integer. Respondents with final scores of 1 were assigned to the beginner map expertise group, scores of 2 to the competent map expertise group, and scores of 3 to the proficient map expertise group.

Table 3-1: Map expertise calculations table (example).

Respondent	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Total	Avg.	Final	User Group
1	3	3	3	3	3	3	2.5	20.5	2.92	3	Proficient
2	2	2	3	3	1	2	3	16	2.28	2	Competent
3	2	3	3	1	1	1	2	13	1.85	2	Competent
4	2	2	1	1	1	1	1	9	1.28	1	Beginner
5	3	3	3	3	3	2	2.5	19.5	2.78	3	Proficient

3.4 Map Reading

The map reading section of the survey measured respondents' map reading performance. Eighteen maps, legends and survey questions were created. The following sub-sections discuss how the maps and survey questions were designed, as well as describe the independent (cause) and dependent (effect) variables of the evaluation. The maps, legends and survey questions from the map reading section are included in Appendix C.

3.4.1 Creating the Maps

Basemaps were collected from ESRI's ArcGIS Online basemap gallery[5], specifically: light grey canvas, topographic, and street basemap types (Figure 3-1). Each basemap layer was imported into the 'Map' viewer, where screenshots were taken, and saved as .png type image files. As a result, the survey maps were static (non-interactive) rather than dynamic (interactive). Basemap image files were then transferred to paint.net[6] where contrast enhancements (for varying screen resolutions) and resizing (to 600 x 400 pixel resolutions) were done. No basemap content was edited.

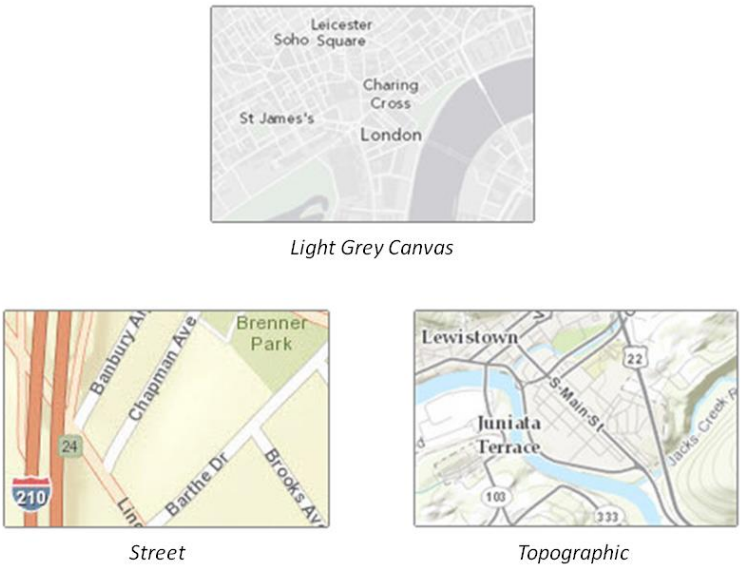

Figure 3-1: ESRI's light grey canvas, street and topographic basemaps.

5 https://www.arcgis.com/home/gallery.html
6 https://www.getpaint.net/doc/latest/index.html

Maps featured different geographic locations in New Zealand. Basemap geography was varied because studies suggest that a range of geographies are used in cartographic design evaluations (Raposo & Brewer, 2014). In turn, basemap cartography (i.e., number of features, types of features, and level of detail/generalization) also varied. This variation was necessary for different levels of map complexity to be compared. Although the basemaps had different geographic locations (and cartography), these conditions were not evaluated in this study.

Once basemaps were collected, thematic content was created for each basemap. Thematic content was created using paint.net. Two styles of thematic content were used: abstract symbols, and pictogram markers. The abstract symbols consisted of basic geometric shapes (i.e., circles, diamonds, and pins), while the pictogram markers consisted of popular map symbols (i.e., information centres, trails, hazards, etc.) – both styles used varying shapes and colours (Figure 3-2 and Figure 3-3).

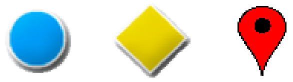

Figure 3-2: Abstract symbols used on survey maps (examples).

Figure 3-3: Pictogram markers used on survey maps (examples).

Symbol and pictogram designs were based on popular web map and topographic map symbologies to reduce the likelihood of thematic content being misunderstood. Legends were created to ensure that respondents understood the thematic content (Figure 3-4).

Figure 3-4: Map with legend.

All thematic content was fictional (i.e., not representing actual locations or features in the real world). Different thematic content was used to remove any familiarity effects between maps. Studies show that repetition may cause users to identify content faster when shown in succession (Flavián et al., 2006). In this regard, respondents' response times could potentially be affected. Although different thematic content was used, the effects of using various thematic data were not evaluated in this study.

3.4.2 Questions and Tasks

A single multiple-choice survey question was presented with each map (18 in total). Each question asked respondents to identify the number of specific thematic content shown on the map, and select the correct answer from the options provided. Five answer options were available for each question. The first four options were numbers (e.g., "1", "3", "5" or "7"), while the fifth option was "Unsure". The "Unsure" option was added to prevent guessing. Numbers were used to reduce time spent reading answers, as suggested by Yan and Tourangeau (2008).

To answer the survey questions, respondents were required to perform search tasks (i.e., visually search for specified thematic content). Tasks are the means for achieving a specific goal (Maguire, 2001). Search tasks are a type of map use task used for retrieving information from the map (Board, 1978; McCann, 1982). Other types of map use tasks include: identifying, comparing, planning, orienting, etc. (Board, 1978; McCann, 1982). With user testing, it is crucial that map use tasks are appropriate for the map being evaluated (Board, 1978).

Search-based tasks were chosen because researchers often use search tasks in map reading experiments (Agrawala & Stolte, 2001; McCann, 1982; Wolfe, 1994). Furthermore, search tasks are relatively simple to perform (van Elzakker, 2004). Studies show that when tasks are difficult, users may make more mistakes, and take longer to complete tasks (Campbell, 1988; Crossland et al., 1995). For these reasons, search tasks were considered an appropriate map use task for this study.

Two types of search tasks were used: search, and search-along-route. Search tasks required respondents to search for specified features shown anywhere on the map. Search-along-route tasks required respondents to search for specified features along, or intersecting with specified routes. Two types of search tasks were used because alternating between tasks can make a survey feel less monotonous, and avoid potential learning curves (Galesic & Bosnjak, 2009; Gerber et al., 1992).

Highlighting and beginning/ending route marker symbols (‘A’ and ‘B’) were created to help respondents identify specified routes (Figure 3-5). However, these enhancements were not used on all maps (i.e., if place names were used instead of ‘A’ and ‘B’ markers).

Figure 3-5: Highlighting and beginning/ending route marker symbols.

Survey questions were designed so that respondents would use the basemap to correctly answer each question. For example, Map Reading Question 9 asked: "How many traffic accidents have been reported between Wharewaka and Hatepe?" (Figure 3-6). To answer this question correctly, respondents needed to first locate Wharewaka and Hatepe on the basemap. Next, they needed to identify the route connecting the two locations. Once identified, respondents could determine how many accidents were present between these two locations. This method ensured that respondents' map reading performance, and basemap usability, was assessed from respondents' accuracy scores, and response times.

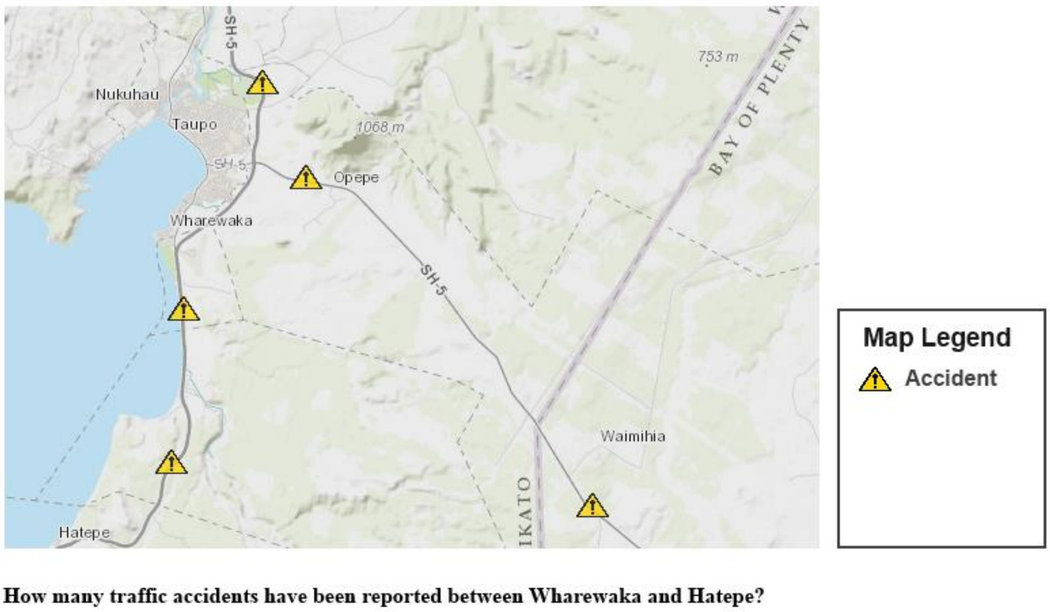

Figure 3-6: Map Reading Question 9.

3.4.3 Independent Variables

The independent variables for this study were: basemap type, map scale, map complexity, map use task, and map expertise. All independent variables were nominal values (i.e., classified by name). Basemap type, map scale and map complexity variables were conditions of the map(s). The map use task variable was associated with how respondents' used the map(s). Map expertise was a respondent variable. Each independent variable contained 2-3 sub-categories. For example, basemap type sub-categories were: canvas, topographic, and street.

Independent variable map sub-categories were distributed across the survey maps as follows. Six of each basemap type sub-category (canvas, topographic, and street), nine of each map scale sub-category (large scale, and small scale), and six of each map complexity sub-category (low, medium, and high) were used across the 18 maps. A graphic representation showing the distribution of independent variable sub-categories is shown in Figure 3-7.

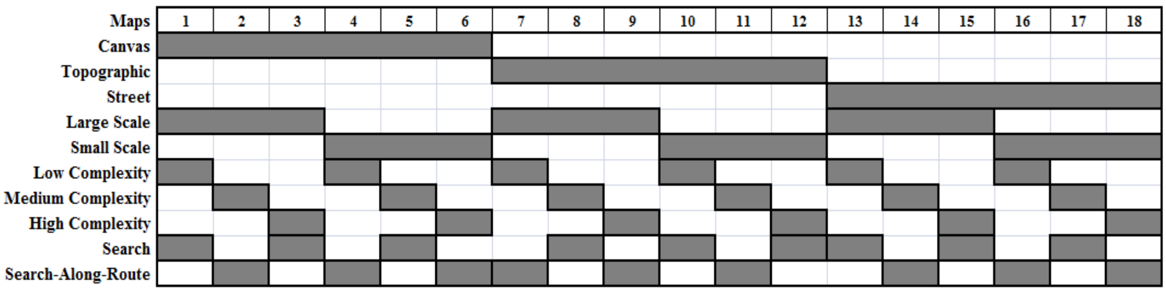

Figure 3-7: Distribution of independent variable sub-categories.

To ensure that independent variable sub-categories were evenly compared, maps were designed as follows. For each map featuring a different basemap type (6 each), three had large scales, and three had small scales. For each of those three maps (different basemap type and map scale), one map had low map complexity, another had medium map complexity, and the remaining had high map complexity. Map use task sub-categories were divided across the maps (survey questions) as evenly as possible. As a result, no two maps had identical independent variables. In turn, each basemap type was compared across both map scales, all levels of map complexity, and using both map use tasks. Each independent variable is detailed in the sub-sections to follow.

3.4.3.1 Basemap Type

Basemap type included: street, topographic, and canvas sub-categories. Basemap usability was assessed by comparing how respondents' accuracy scores and response times varied between maps with different basemap types.

3.4.3.2 Map Scale

Map scale included: large scale, and small scale sub-categories. To determine how scale affected map usability, respondents' accuracy scores and response times were compared between maps with different map scales.

Representative Fraction (RF) scales were used to determine large and small scale sub-categories. These scales were calculated for each map by comparing distances on the map with distances in the real world. Map scales within each sub-category were not identical. Large scale maps ranged from ~1:10,000 to ~1:28,000, while small scale maps ranged from ~1:50,000 to ~1:230,000. These differences in map scale were the result of adjustments made to create similar map complexity groups.

3.4.3.3 Map Complexity

Map complexity included: low, medium, and high map complexity sub-categories. To determine how map complexity affected map usability, respondents' accuracy scores and response times were compared between maps with different levels of map complexity.

The map complexity sub-categories were created by counting four types of criteria: 1) map features, 2) feature representations, 3) labels, and 4) colours (Figure 3-8). These criteria were chosen because they are identified as common map complexity criteria within the literature (Edler et al., 2014; Fairbairn, 2006; Stigmar & Harrie, 2011). Map complexity scores were determined for each map by counting the number map complexity criteria shown on the map(s) – including the basemap, and thematic content. Map complexity criteria were manually counted by the researcher.

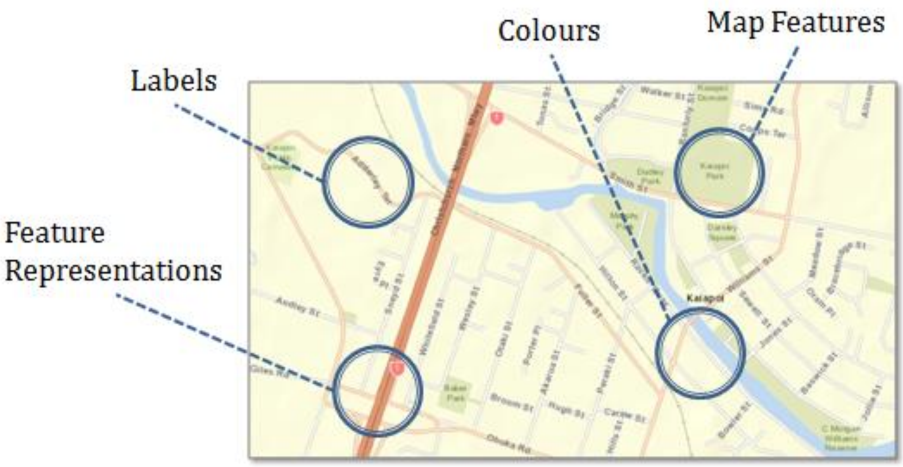

Figure 3-8: The four map complexity criteria.

Map complexity criteria 1, map features, measured the total number of features on the map(s). Map features were: points, lines, and polygons. When features intersected or overlapped one another, features were split up and counted separately. For example, if a line feature (*x* to *y)* was intersected by another line feature (*a* to *b*), the lines were counted separately from where they intersected (Figure 3-9).

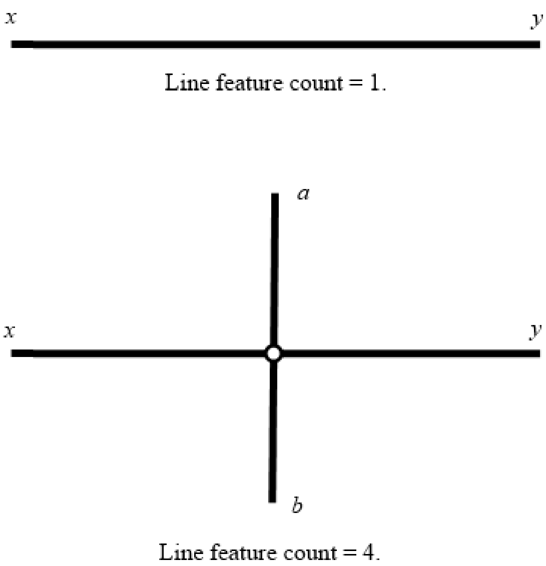

Figure 3-9: Separating and counting line map features (example).

Map complexity criteria 2, feature representations, measured the total number of unique symbologies on the map(s). For example, if three road symbologies were shown (e.g., roads, main roads, and motorways), then three feature representations were counted.

Map complexity criteria 3, labels, measured the total number of labels on the map(s). If two or more words were used to label a feature, they were regarded as a single label. For example, the label "Mount Cook" was counted as a single label criteria.

Map complexity criteria 4, colours, measured the total number of colour hues on the map(s). Colour hues were determined by the researcher, therefore, colour measurements were subjective. Colour variations shown on background relief and terrain were disregarded.

Using these map complexity criteria, map complexity scores were calculated for all survey maps. Map complexity sub-categories were created by grouping maps with relative map complexity scores. Overall, map complexity scores ranged from 52 to 243. Ranges for each map complexity sub-category were: low 52-68, medium 144-168, and high 200-243. Figure 3-10 shows the spreadsheet used for calculating map complexity scores.

Map Complexity Table

		Map Features		Feature Representations		Labels		Colour			Complexity Score	Complexity Sub-Category
ID	Basemap Type	Layers	Basemap	Layers	Basemap	Layers	Basemap	Layers	Basemap	Labels		
1	Canvas	15	16	4	6	0	5	3	6	2	57	LOW
2	Canvas	4	121	1	7	0	3	1	4	3	144	MEDIUM
3	Canvas	8	20	4	5	2	3	3	6	1	52	LOW
4	Canvas	17	129	5	3	2	33	6	4	1	200	HIGH
5	Canvas	14	122	3	7	2	4	3	4	3	162	MEDIUM
6	Canvas	18	178	4	6	0	18	2	4	3	233	HIGH
7	Topographic	2	136	2	11	0	40	2	11	3	207	HIGH
8	Topographic	9	22	5	8	0	7	2	8	3	64	LOW
9	Topographic	16	117	5	7	0	12	3	6	2	168	MEDIUM
10	Topographic	5	32	1	7	0	13	2	6	2	68	LOW
11	Topographic	15	115	2	9	0	11	3	7	2	164	MEDIUM
12	Topographic	16	131	3	14	0	40	2	10	4	220	HIGH
13	Streets	25	151	2	5	0	49	3	4	4	243	HIGH
14	Streets	8	17	2	6	0	19	2	7	4	65	LOW
15	Streets	9	24	4	8	0	8	3	8	3	67	LOW
16	Streets	11	101	3	7	0	24	3	7	4	160	MEDIUM
17	Streets	9	104	2	9	2	29	3	7	3	168	MEDIUM
18	Streets	17	141	3	10	0	51	2	9	5	238	HIGH

Figure 3-10: Map complexity calculations table.

3.4.3.4 Map Use Task

Map use task included: search, and search-along-route sub-categories. These tasks were designed into the map reading survey questions. To determine how map use task affected map usability, respondents' accuracy scores and response times were compared between survey questions using different map use tasks.

3.4.3.5 Map Expertise

Map expertise included: beginner, competent, and proficient sub-categories. Respondents' map expertise was determined from their responses to the map expertise survey questions. To determine how map expertise affected respondents' map reading performance, accuracy scores and response times were compared between each map expertise group.

3.4.4 Dependent Variables

The dependent variables for this study were: accuracy, and response time. These variables were recorded for each survey question. Accuracy and response time variables are commonly used for measuring usability in the literature (Crossland et al., 1995; Nielsen, 1993; Phillips, 1979).

Accuracy scores were recorded as binary numbers (i.e., 0 or 1). These numbers were reclassified as either 'incorrect' (0), or 'correct' (1). Response times were continuous, and measured in seconds. Qualtrics measures response times using client-side paradata. Client-side paradata is the elapsed time from when a survey question is fully displayed on the respondent's computer, to when an answer is sent by the respondent (Yan & Tourangeau, 2008). In turn, response times measured from when survey pages were fully displayed on the respondents' computers, to when respondents' clicked on the 'Next' button.

3.5 Basemap Preference

The basemap preference section recorded respondents' subjective preferences for ESRI's canvas, topographic, and street basemap types. Respondents' basemap preferences were compared between basemap types, as well as map expertise groups. All basemaps from the basemap preference section are included in Appendix D.

Twenty-seven basemaps were shown across 9 different geographic locations in New Zealand. Locations included: Auckland, Christchurch, Fairlie, Fiordland, Huntly, Rotorua, Thames, Waikawa, and New Zealand. Each location was represented by a canvas, topographic and street basemap (Figure 3-11).

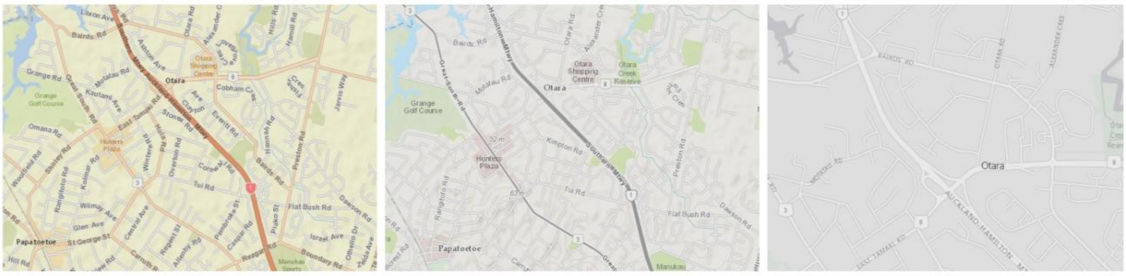

Figure 3-11: Auckland basemaps (example).

Basemaps were shown on different pages of the survey to ensure that subjective preferences were measured independently (i.e., basemaps were not compared side-by-side). Basemaps were also arranged so that respondents would not rate the same basemap type or geographic location in succession. In turn, respondents were (presumably) less likely to recognize identical geographic locations.

3.5.1 Preference Questions

Respondents' basemap preferences were recorded using Likert scales (Figure 3-12). Each survey question asked respondents to rate the likeability of the basemap shown. Likert scales have been used in the literature to record map users' subjective preferences (Fabrikant et al., 2012; You et al., 2007).

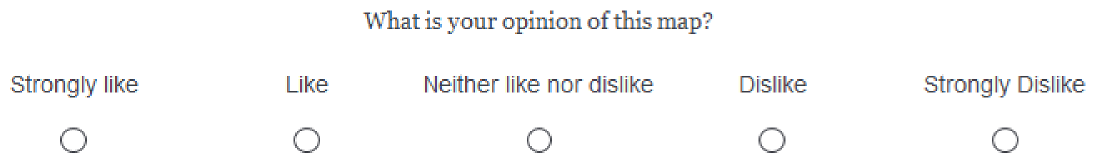

Figure 3-12: Basemap preference survey question(s).

3.6 Analysis Methods

The online survey was designed for quantitative statistical analysis. Survey data was analyzed using SPSS version 23, and a statistical significance threshold of $p<.05$ was used. Statistical analyses were run for both the accuracy and response time datasets. Once map expertise groups had been established, accuracy and response time statistical analyses were run for each map expertise group. Respondents' basemap preferences were compared overall, and between map expertise groups. The statistical analysis methods used for analyzing respondents' map reading performance, and basemap preferences, are discussed in the following sub-sections.

3.6.1 Map Reading Analysis

A Generalized-Linear Mixed-Effects Model (GLMM) was used to determine how independent variables (basemap type, map scale, map complexity, map use task, and map expertise) affected dependent variables (accuracy scores, and response times). A GLMM was used because it allowed for nominal independent variables, as well as fixed and random effects, to be analyzed.

Fixed effects are experimental factors entirely represented in a dataset, and are controlled by the researcher. Fixed effects were: basemap type, map scale, map complexity, map use task, and map expertise. Random effects are sampled experimental factors representative of a larger population, and are not controlled by the researcher. Random effects were: survey respondents, and survey questions. A GLMM was the only statistical model capable of simultaneously analyzing multiple independent and dependent variables, as well as both fixed, and random factors.

A binomial logistic regression method was used within the GLMM to analyze accuracy scores. As defined by Lund and Lund (2016), “a binomial regression is a way to predict the probability of an observation falling into one of two categories of a dichotomous dependent variable, based on one or more independent variables that can be either continuous or categorical.” As accuracy scores were categorically dichotomous (correct or incorrect), the binomial logistic regression method was appropriate.

A linear regression method was used within the GLMM to analyze response times. A linear regression predicts the value of a dependent variable based on the value of an independent variable (Lund & Lund, 2016). As response times were measured on a continuous scale (seconds), the linear regression method was appropriate.

The GLMM statistical analysis produced results for independent variables, independent variable sub-categories, as well as variable interactions. The independent variable results were produced by averaging the independent variable sub-categories within that variable. Variable interactions were produced to test for possible carryover effects (a consequence of comparing many independent variables simultaneously). Pairwise interactions (two-way) were used to compare statistics between sub-categorical items within the independent variables (e.g., canvas vs. topographic, canvas vs. street, topographic vs. street). Three-way interactions were not used because they are more difficult to interpret (e.g., canvas vs. topographic vs. street).

The outputs of the GLMM were: F statistics, p-values, contrast estimates (accuracy), parameter estimates (response time), mean scores, standard errors, and confidence intervals. Contrast estimates compare dependent variables between two independent variables to estimate a statistical trend. Parameter estimates predict how changes in independent variables may affect dependent variables. In turn, specific independent variables are used as intercepts (i.e., the expected mean value) for parameter estimates.

3.6.2 Basemap Preference Analysis

Descriptive statistics were used compare respondents’ basemap preferences, specifically: mean, and scaled mean scores. These statistics were produced by analyzing respondents’ answers on the 5-point Likert scales. To do this, each answer option on the Likert scales were weighted between 1 and 5. The “Strongly like” option was given a weight of 1, and the “Strongly dislike” option a weight of 5 (with options in between scaled accordingly). An inverse correlation between high scores and respondents’ basemap preferences was produced (i.e., lower mean scores represented favourable basemap preferences, and higher mean scores represented unfavourable basemap preferences).

Cronbach’s alpha (α) statistics were used to validate the independency of basemap preferences. According to Tavakol and Dennick (2011), Cronbach’s α can be used to measure internal consistency within a test or scale, and indicate if a test is measuring constructs independently. In this study, basemap types were the constructs being measured.

Cronbach’s α produced scores between 0 and 1 – the higher the score, the more reliable the measurement for that construct. Researchers suggest using Cronbach’s α scores of 0.7 or greater (George, 2003; Pallant, 2010; Tavakol & Dennick, 2011). If Cronbach’s α scores are less than 0.7, tests may need to be re-examined to ensure they are measuring constructs independently.

3.7 Recruitment

Survey respondents were recruited through email, social media and printed advertisements. Email advertisements were distributed to geography students at the University of Canterbury, and Victoria University of Wellington. Social media advertisements were posted on Facebook, Twitter and LinkedIn. Printed advertisements were displayed at public locations around the University of Canterbury.

The survey was made as short as possible to encourage high response rates. No reward or incentive was offered to respondents for their participation. Furthermore, no requirements were enforced to take the survey.

3.8 Assumptions

The online survey was easy to access and distribute; however, the testing environment (each respondent's computer/surroundings) was not supervised, or controlled. As a result, respondents' computers were not identical, and potential distractions were not removed from the testing environment.

Several experimental assumptions were made to negate possible differences in respondents' computers, environments, and ability to follow instructions. First, it was assumed that different computer processing abilities, screen/monitor sizes, screen/monitor resolutions, mouse response/sensitivity, and internet connectivity had no significant effect on results. Second, it was assumed that respondents' environments (i.e., location where survey was taken) were identical, and distractions were minimum. Respondents were instructed to take the survey independently, and recommended to complete the survey from start to finish without pause. In turn, these requests were also assumed true.

Chapter Summary

The online survey was designed to investigate and compare the usability of ESRI's canvas, topographic, and street basemaps. Basemap usability was assessed by comparing respondents' map reading performance, and subjective preferences, for each of the three basemap types. Comparisons were made across effectiveness (accuracy), efficiency (response time), and satisfaction (basemap preference) usability metrics. In addition to basemap type, the survey examined how map scale, map complexity, map use tasks, and map expertise affected respondents' map reading performance. By evaluating how basemap type and other variables affected respondents' map reading performance and basemap preferences, basemap usability could be determined.

Chapter 4 - Results

The online survey, outlined in Chapter 3, launched in October, 2015. The survey was active for three months. Demographic and map expertise information was collected using multiple-choice survey questions. Map reading performance was assessed based on accuracy scores and response times for survey questions involving maps. Basemap preferences were assessed using Likert scales.

This chapter presents the results from the online survey. Demographic and map expertise information is covered first. Next, map reading results and basemap preferences are shown. Figures and tables are used to present the results where appropriate. Map reading and basemap preference results are also compared between map expertise groups.

4.1 Demographic Results

One-hundred and eighty-seven respondents initiated the survey, and 137 (73%) completed it. Incomplete survey data was discarded. The survey took respondents 10 to 20 minutes to complete on average.

Of the 137 survey respondents, 67 (49%) were male, and 70 (51%) were female. Fifty-one respondents (37%) were between 20-29 years of age (Figure 4-1). One-hundred and seven respondents (78%) had completed a university degree (Figure 4-2). Most respondents (74%) were based in New Zealand. Twelve per cent of respondents were based in the United States, and all other countries comprised less than 5%.

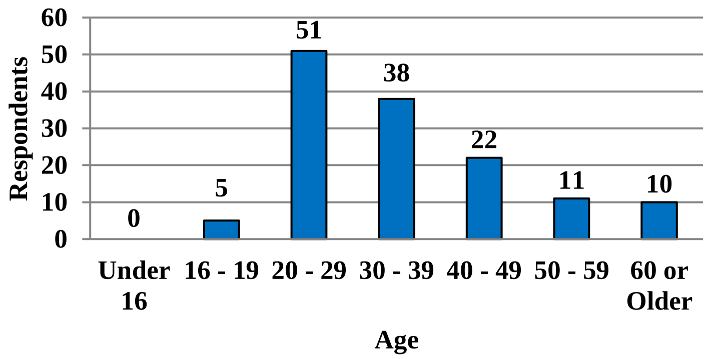

Figure 4-1: Survey respondents by age group.

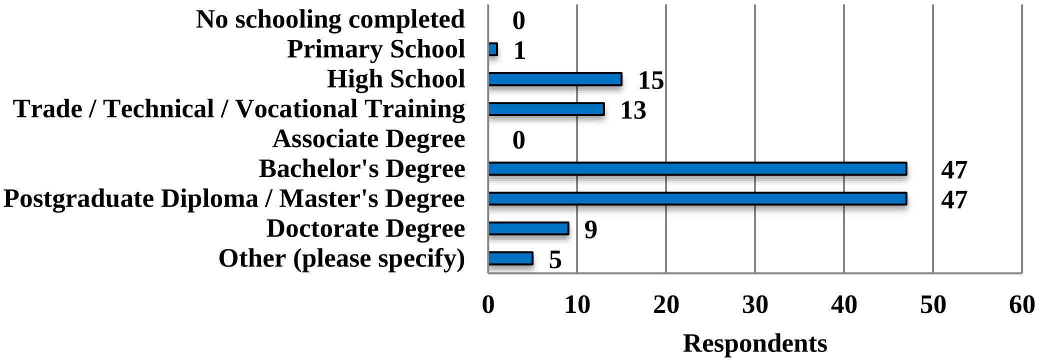

Figure 4-2: Survey respondents by education level (highest completed qualification).

Presumably, a large number of geography students and professional map users took the survey. This theory is in line with the survey recruitment methods. Moreover, the nature of the study likely attracted individuals interested in maps.

4.2 Map Expertise Results

Map expertise calculations show 37 respondents (27%) as beginner, 54 (39%) as competent, and 46 (34%) as proficient (Figure 4-3). Each of the map expertise survey questions are presented within this sub-section. Total responses and expertise group distributions are shown for each question.

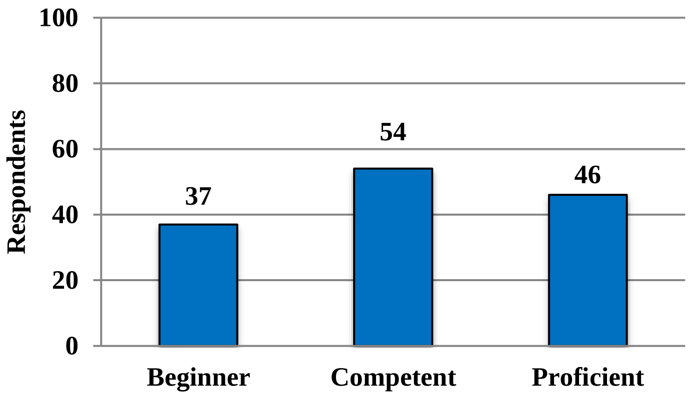

Figure 4-3: Map expertise group distributions.

Question 1 asked respondents to categorize themselves into one of five map expertise groups. Fifty respondents (36%) categorized themselves as competent, 34 (25%) as proficient, and 29 (21%) as expert (Figure 4-4). Expertise group distributions show that answers generally matched the calculated expertise group for each respondent.

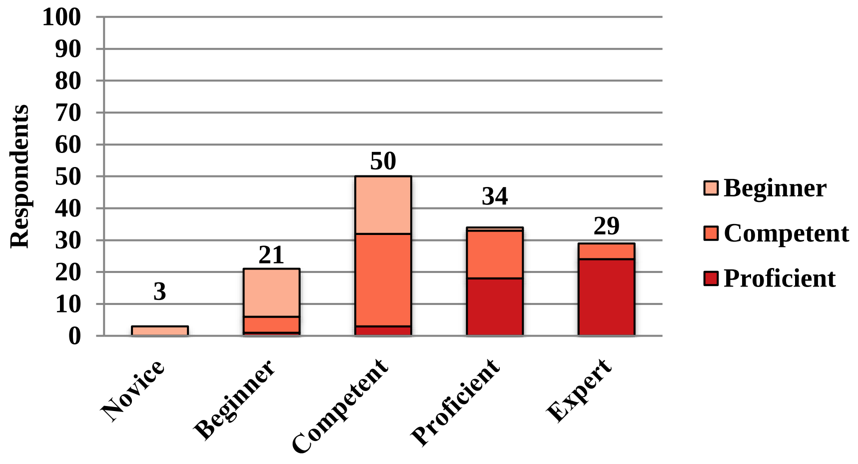

Figure 4-4: Map expertise question 1 – self-selection.

Question 2 asked respondents how often they used maps. Forty-nine respondents (36%) reported using maps every day (Figure 4-5). Expertise group distributions show that beginner respondents were less frequent map users, while proficient respondents were more frequent map users.

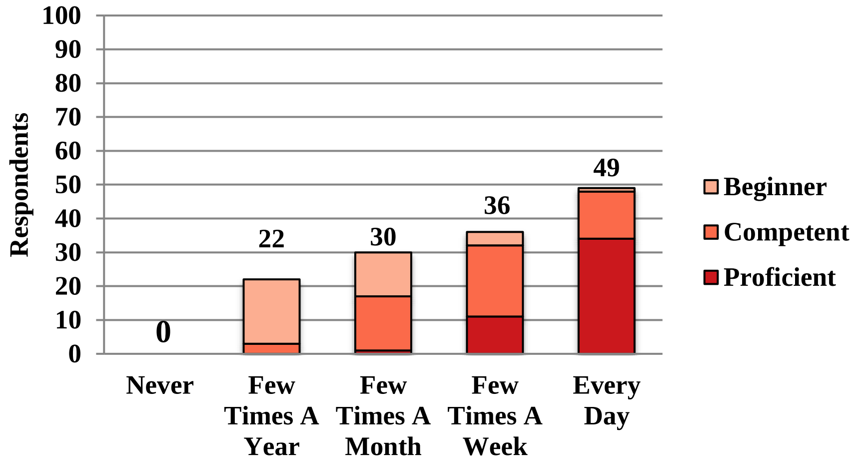

Figure 4-5: Map expertise question 2 – map usage.

Question 3 asked respondents if they had ever been trained to use maps. Eighty-five respondents (62%) had received training, and 52 (37%) had not (Figure 4-6). Expertise group distributions show that most competent and proficient respondents had been trained to use maps, while most beginner respondents had not.

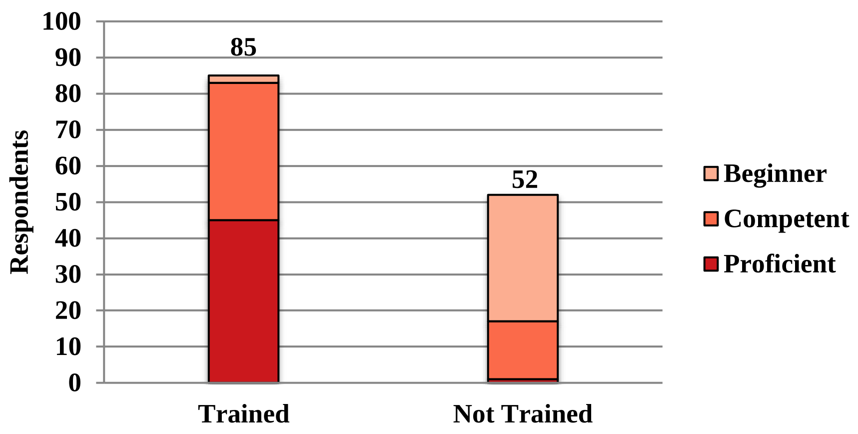

Figure 4-6: Map expertise question 3 – map use training.

Question 4 asked respondents if they had ever been trained to create maps. Seventy-two respondents (52%) had received training, and 65 (47%) had not (Figure 4-7). Expertise group distributions show that nearly all proficient respondents had received training to create maps, while most beginner respondents had not. Competent respondents were evenly divided between the two answer options.

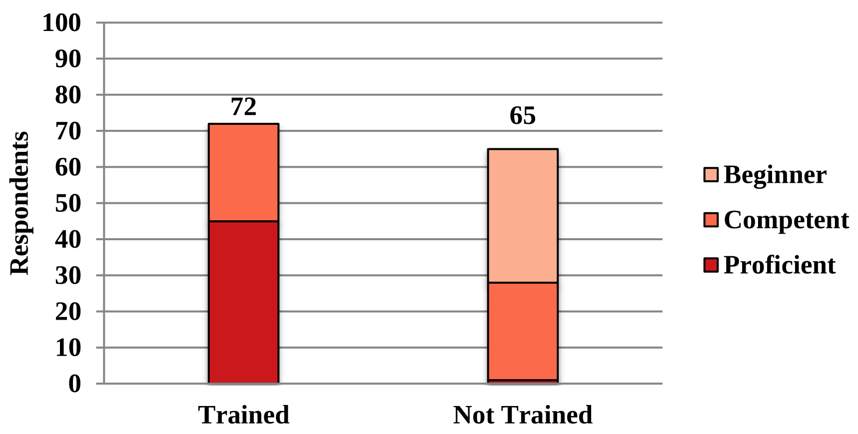

Figure 4-7: Map expertise question 4 – map creation training.

Question 5 asked respondents if they had ever edited, created, or assisted in creating a digital basemap. Forty-three respondents (31%) had edited, created, or assisted in creating a digital basemap (within the last three years), 72 (52%) had not, and 16 (11%) were unsure what a basemap was (Figure 4-8). Expertise group distributions show that the majority of proficient respondents had edited, created, or assisted in creating a digital basemap, while no beginner respondents had done so.

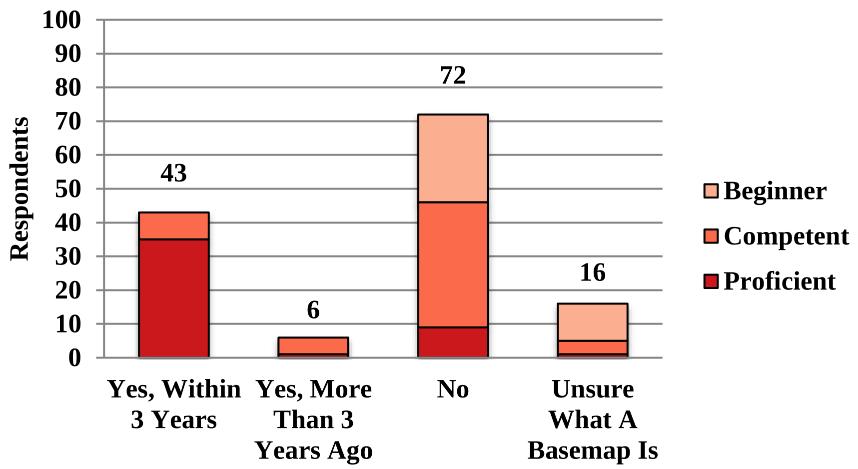

Figure 4-8: Map expertise question 5 – experience creating, or editing basemaps.

Question 6 asked respondents if they had ever created a map on the internet. Forty-two respondents (30%) had created a map on the internet (within the last six months), and 82 (59%) had not (Figure 4-9). Expertise group distributions show that most proficient respondents had created a map on the internet, while most beginner respondents had not.

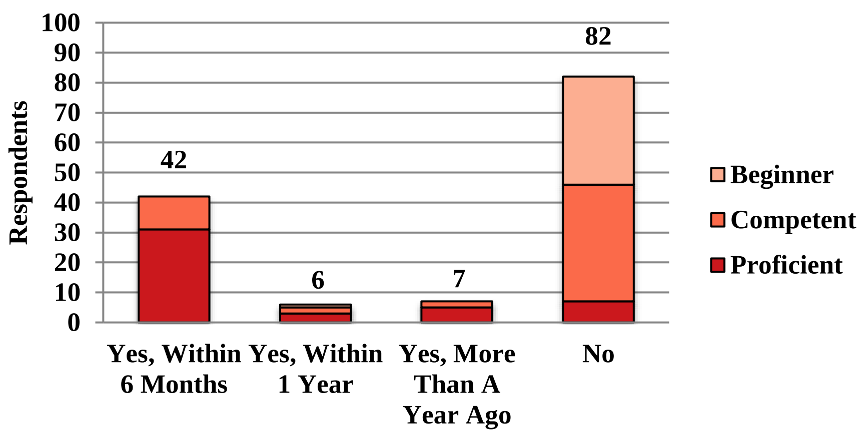

Figure 4-9: Map expertise question 6 – created maps on the internet.

Question 7 asked respondents which types of maps they had used within the past month. Results show that 135 respondents (98%) had used an online map, and 97 respondents (70%) had used a mobile mapping application within the past month (Figure 4-10). All remaining categories were used by less by than 50% of respondents. Expertise group distributions show that all map types were used evenly, suggesting no correlation between map expertise and specific map usage.

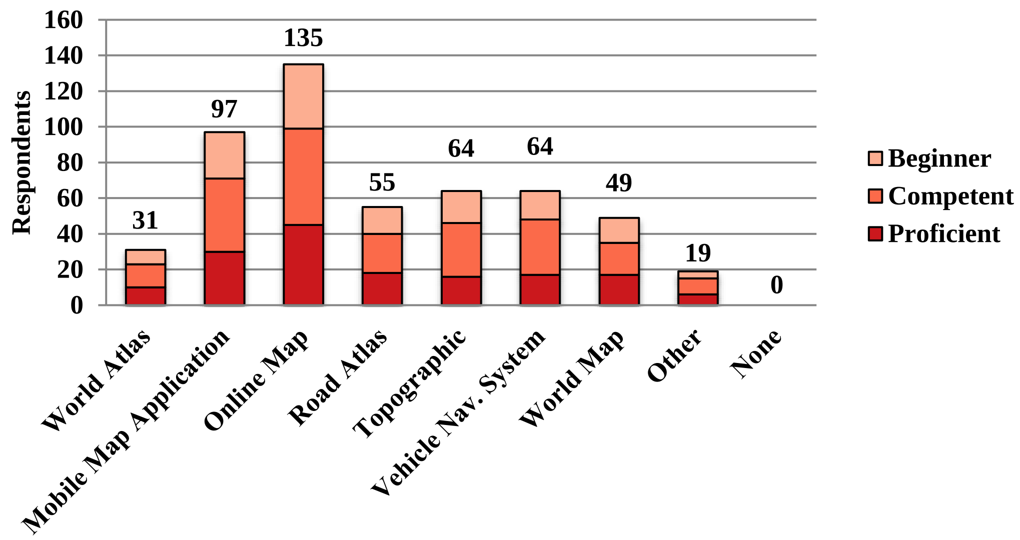

Figure 4-10: Map expertise question 7 – map types used in past month.

4.3 Map Reading Results

Map reading performance was assessed based on respondents' accuracy scores and response times for survey questions (maps). Accuracy results and response time results are presented separately. Specifically, independent variables, independent variable sub-categories, and variable interaction results are shown (where necessary).

The independent variable results show significant effects overall, and may be used to identify where significant effects are present. The independent variable sub-category results show how individual sub-categories (e.g., canvas basemap type, topographic basemap type, etc.) affected dependent variables (accuracy scores, and response times). The variable interaction results compare variables and variable sub-categories for possible carryover effects.

Statistical outputs include: F statistics, p-values (sig.), contrast estimates (accuracy scores), parameter estimates (response times), mean scores, standard errors, and confidence intervals. Contrast estimates compare respondents' accuracy scores between two independent variables to estimate a statistical trend. Parameter estimates predict how changes in independent variables may affect response times. In turn, the parameter estimates use specific independent variables as intercepts (i.e., the expected mean value). Mean scores and confidence intervals are used to show effect sizes for contrast, and parameter estimates.

A statistical significance threshold of $p<.05$ was used. Asterisks (*) identify where significant p-values are shown. Results tables without significant p-values can be found in Appendix E.

4.3.1 Accuracy Results

Respondents answered 90.7% of survey questions correctly. Independent variable results show that map scale had a significant effect ($p=.013$) on accuracy scores (Table 4-1).

Table 4-1: Accuracy results for independent variables.

Variables	**F**	**Sig.**
Basemap Type	.125	.883
Map Complexity	.807	.446
Map Scale	6.215	.013 *
Map Use Task	1.784	.182
Basemap Type *x* Map Complexity	.641	.633
Basemap Type *x* Map Scale	.847	.429
Basemap Type *x* Map Use Task	1.477	.228

The independent variable sub-category results show that respondents were more accurate using large scale maps (p=.039; Table 4-2).

Table 4-2: Accuracy results for independent variable sub-categories.

Variables	Contrast Estimate	Std. Error	Sig.	95% Confidence Interval Lower	Upper
Basemap Type					
Canvas vs Topographic	.001	.050	.987	-.096	.098
Canvas vs Street	.019	.047	.687	-.073	.110
Topographic vs Street	.018	.041	.658	-.062	.098
Map Complexity					
Low vs Medium	.038	.056	.499	-.072	.148
Low vs High	.062	.053	.240	-.041	.165
Medium vs High	.024	.037	.522	-.049	.097
Map Scale					
Large vs Small	.141	.068	.039 *	.007	.275
Map Use Task					
Search vs Search-Along-Route	-.059	.045	.192	-.148	.030

Mean scores and confidence intervals further indicate that respondents were more accurate using large scale maps (Table 4-3).

Table 4-3: Accuracy results for independent variable sub-categories.

			95% Confidence Interval	
Variable	**Mean**	**Std. Error**	**Lower**	**Upper**
Basemap Type				
Canvas	.075	.039	.026	.198
Topographic	.074	.032	.031	.166
Street	.056	.027	.021	.138
Map Complexity				
Low	.105	.048	.041	.241
Medium	.067	.030	.027	.156
High	.043	.024	.014	.122
Map Scale				
Large	.166	.063	.075	.328
Small	.026	.014	.009	.074
Map-Use Task				
Search	.044	.022	.016	.111
Search-Along-Route	.103	.038	.049	.204

Based on these results, this study can infer that basemap type did not significantly affect respondents' map reading effectiveness.

While not statistically significant, results show that respondents were less accurate using street basemap types, and more accurate using canvas basemap types. Additionally, respondents were more accurate using lower complexity maps, and performing search-along-route tasks.

For comparison, the statistical model used a logit link function based on a -2 log likelihood. Criteria summaries were: 14,097.426 (Akaike), and 14,109.018 (Bayesian). Models with smaller criteria values are a better fit.

4.3.1.1 Accuracy Results: Map Expertise

Independent variable results show that map expertise had no significant effect ($p=.517$) on accuracy scores (Table 4-4). The independent variable sub-category results also show no significant effects (Appendix E).

Table 4-4: Map expertise accuracy results for independent variables.

Variables	F	Sig.
Map Expertise	.660	.517
Map Expertise *x* Basemap Type	.141	.967
Map Expertise *x* Map Complexity	1.968	.097
Map Expertise *x* Map Scale	.847	.961
Map Expertise *x* Map Use Task	1.477	.255

4.3.2 Response Times

An initial review of the response time dataset revealed errors, and several significant outliers. As a result, the response time dataset was amended for statistical analysis.

4.3.2.1 Preparing the Response Time Data

The original response time data ranged from 0 to 1,127 seconds (s) for survey questions (Table 4-5). Errors were response times of 0.00s. Skewness (symmetry) and kurtosis (distribution) measurements indicated that significant outliers were present. For example, a ‘perfect’ normal distribution would have skewness and kurtosis values of 0. Figure 4-11 shows a histogram of the original response time data. Response time results are shown in seconds

Table 4-5: Original response time data with errors and outliers.

N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
2,466	0.00	1127.76	23.53	33.95	18.63	515.69

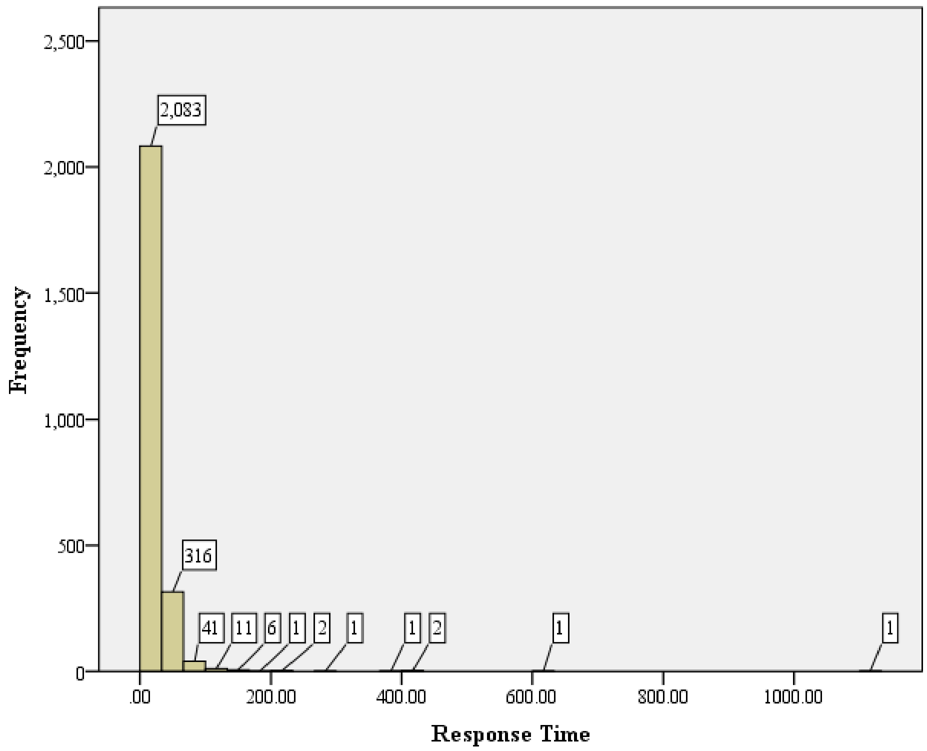

Figure 4-11: Histogram of original response time data with errors and outliers (SPSS).

Errors and outliers were manually removed by the researcher. Response times less than 5s were removed because pilot testing determined that respondents could not submit appropriate answers within this time. Response times greater than 60s were removed because pilot testing suggested that these durations were caused by spurious effects, specifically: interruptions, computer issues, unsolicited breaks, etc. In total, 192 errors and outliers (7% of response times) were removed.

Descriptive statistics for the amended response time data are shown in Table 4-6. Figure 4-12 shows a histogram of the amended response time data. While the amended histogram does not appear normal (Gaussian), this distribution (rapid rise on left with long tail on right) is typical for most response time datasets (Whelan, 2008). The amended response time dataset was used for statistical analysis.

Table 4-6: Amended response time data.

N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
2,319	5.06	59.94	20.41	10.79	1.22	1.26

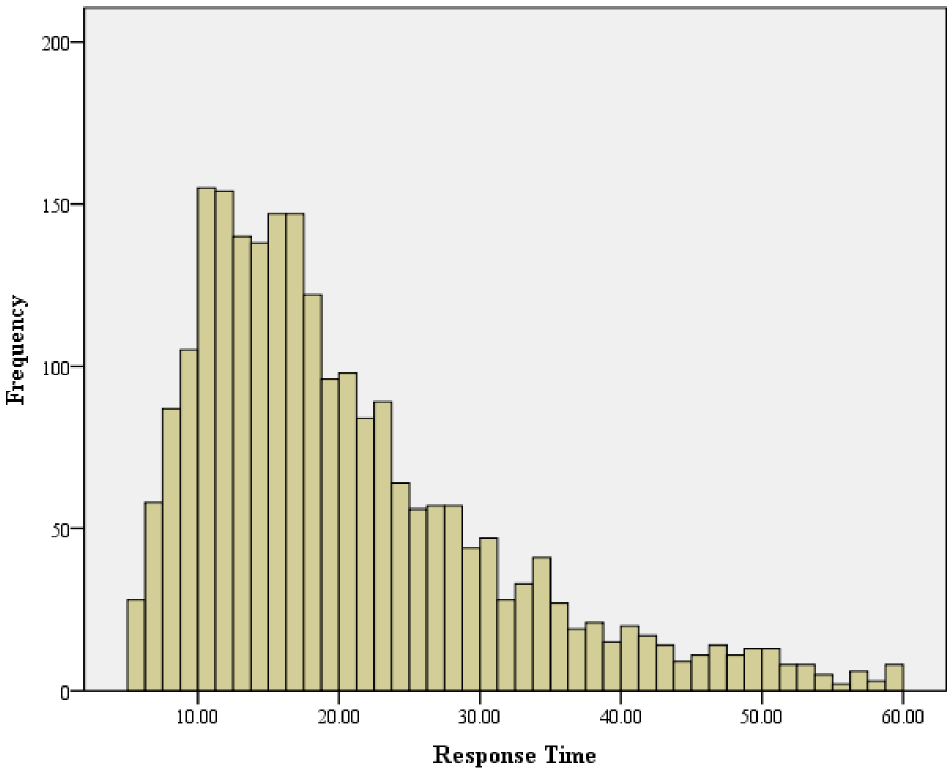

Figure 4-12: Histogram of amended response time data (SPSS).

4.3.3 Response Time Results

Independent variable results show that map use task had a significant effect (p=.054) on response times (Table 4-7). A significant interaction effect was also found between basemap type and map complexity variables (p=.035). Response time results are shown in seconds (excluding overall independent variable results).

Table 4-7: Response time results for independent variables.

Variables	**F**	**Sig.**
Basemap Type	.223	.813
Map Complexity	5.141	.107
Map Scale	3.131	.175
Map Use Task	9.514	.054 *
Basemap Type *x* Map Complexity	11.885	.035 *
Basemap Type *x* Map Scale	2.762	.210
Basemap Type *x* Map Use Task	.490	.655

The independent variable sub-category results show that respondents completed search tasks only ~1.5s faster (p=.444) than search-along-route tasks (Table 4-8). These results indicate that map use tasks did not significantly affect response times. Incidentally, results revealed that response times were ~8s slower (p=.041) for street basemap types.

Table 4-8: Response time results for independent variable sub-categories.

Variables	Parameter Estimate	Std. Error	t	Sig.	95% Confidence Interval Lower	95% Confidence Interval Upper
Intercept	18.236	1.910	9.546	.000	13.607	22.864
Basemap Type						
Canvas	-2.898	2.318	-1.250	.290	-9.805	4.009
Topographic	–	–	–	–	–	–
Street	7.900	2.437	3.241	.041 *	.602	15.199
Map Complexity						
Low	-4.562	1.924	-2.370	.083	-10.122	.997
High	.388	1.924	.202	.851	-5.173	5.950
Medium	–	–	–	–	–	–
Map Scale						
Large	3.673	1.679	2.187	.099	-1.114	8.462
Small	–	–	–	–	–	–
Map Use Task						
Search	-1.429	1.665	-.859	.444	-6.249	3.390
Search-Along-Route	–	–	–	–	–	–

Mean scores and confidence intervals, however, show that response times between basemap types were only ~1s apart (Table 4-9). These results indicate that basemap type did not significantly affect response times.

Table 4-9: Response time results for independent variable sub-categories.

Variable	Mean	Std. Error	95% Confidence Interval Lower	Upper
Basemap Type				
Canvas	20.340	1.052	17.663	23.016
Topographic	20.336	.909	18.151	22.522
Street	21.002	.960	18.646	23.359
Map Complexity				
Low	20.002	.960	17.645	22.358
Medium	22.601	.909	20.415	24.787
High	19.075	1.050	16.398	21.753
Map Scale				
Large	21.738	.902	19.576	23.899
Small	19.381	1.030	16.777	21.985
Map Use Task				
Search	18.818	.967	16.430	21.207
Search-Along-Route	22.300	.830	20.381	24.220

Based on these results, this study can infer that basemap type did not significantly affect map reading efficiency. Although parameter estimates predicted (significantly) slower response times for street basemap types, the confidence intervals show no pronounced differences between basemap types.

While not statistically significant, results show that respondents had faster response times using canvas basemap types, and slower response times using street basemap types. The parameter estimates show that respondents were ~4.5s faster using low complexity maps; however, the mean scores and confidence intervals do not show this effect. Medium complexity maps were answered the slowest. Response times were also slower for large scale maps, and search tasks.

Variable interactions are presented (Table 4-10) because a significant interaction effect was observed between basemap type and map complexity variables (p=.035; Table 4-7). Parameter estimates show that response times were ~10.5s slower (p=.028) for low complexity canvas basemaps. Furthermore, response times were ~11s faster (p=.025) for medium complexity street basemaps.

Table 4-10: Response time results for independent variable sub-category interactions.

Variable Interactions		Parameter Estimate	Std. Error	t	Sig.	95% Confidence Interval Lower	95% Confidence Interval Upper
Intercept		18.236	1.910	9.546	.000	13.607	22.864
Basemap Type	*Map Complexity*						
Canvas	Low	10.415	20593	4.016	.028 *	2.156	18.673
Canvas	Medium	.228	3.033	.075	.945	-9.486	9.943
Canvas	High	–	–	–	–	–	–
Topographic	Low	–	–	–	–	–	–
Topographic	Medium	–	–	–	–	–	–
Topographic	High	–	–	–	–	–	–
Street	Low	-3.801	2.748	-1.383	.261	-12.568	4.964
Street	Medium	-10.855	2.591	-4.188	.025 *	-19.119	-2.591
Street	High	–	–	–	–	–	–
Basemap Type	*Map Scale*						
Canvas	Large	.617	3.545	.174	.873	-10.714	11.949
Canvas	Small	–	–	–	–	–	–
Topographic	Large	–	–	–	–	–	–
Topographic	Small	–	–	–	–	–	–
Street	Large	-5.309	2.424	-2.190	.117	-13.040	2.421
Street	Small	–	–	–	–	–	–
Basemap Type	*Map Use Task*						
Canvas	Search	-3.001	3.032	-.990	.396	-12.717	6.714
Canvas	Search-Along-Route	–	–	–	–	–	–
Topographic	Search	–	–	–	–	–	–
Topographic	Search-Along-Route	–	–	–	–	–	–
Street	Search	-.847	2.179	-.389	.724	-7.808	6.113
Street	Search-Along-Route	–	–	–	–	–	–

Mean scores and confidence intervals show that response times were slower for low complexity canvas basemaps (Table 4-11); however, response times were slowest for medium complexity street basemaps. These results differ from the previous parameter estimates.

Table 4-11: Response time results for independent variable sub-category interactions.

Variable Interactions		Mean	Std. Error	95% Confidence Interval Lower	Upper
Basemap Type	*Map Complexity*				
Canvas	Low	23.999	1.402	20.141	27.857
Canvas	Medium	18.388	1.393	14.516	22.260
Canvas	High	18.633	2.108	12.304	24.962
Topographic	Low	17.128	1.394	13.258	20.998
Topographic	Medium	21.932	1.395	18.063	25.801
Topographic	High	21.949	1.394	18.078	25.819
Street	Low	18.878	1.668	14.065	23.692
Street	Medium	27.484	1.399	23.621	31.346
Street	High	16.645	1.394	12.775	20.515
Basemap Type	*Map Scale*				
Canvas	Large	22.609	1.394	18.738	26.480
Canvas	Small	18.070	2.303	11.116	25.024
Topographic	Large	22.297	1.208	19.083	25.511
Topographic	Small	18.376	1.205	15.158	21.593
Street	Large	20.308	1.525	16.001	24.615
Street	Small	21.697	1.096	18.869	24.524
Basemap Type	*Map Use Task*				
Canvas	Search	17.739	1.973	11.875	23.603
Canvas	Search-Along-Route	22.940	1.292	19.433	26.447
Topographic	Search	19.237	1.206	16.021	22.453
Topographic	Search-Along-Route	21.436	1.206	18.220	24.652
Street	Search	19.479	1.217	16.231	22.727
Street	Search-Along-Route	22.526	1.217	19.277	25.774

The variable interaction results may suggest that particular maps, rather than variable sub-categories, caused the observed effects. As a result, the variable sub-categories associated with those maps (i.e., map complexity and basemap type) were assumed to have no significant effect on response times.

For comparison, criteria summaries were: 16,629.171 (Akaike), and 16,646.380 (Bayesian). Models with smaller criteria values are a better fit.

4.3.3.1 Response Time Results: Map Expertise

Independent variable results show that map expertise had a significant effect (p=.000) on response times (Table 4-12).

Table 4-12: Map expertise response time results for independent variables.

Variables	F	Sig.
Map Expertise	8.152	.000 *
Map Expertise *x* Basemap Type	1.048	.381
Map Expertise *x* Map Complexity	.650	.627
Map Expertise *x* Map Scale	.096	.908
Map Expertise *x* Map Use Task	1.444	.236

The independent variable sub-category results show that proficient respondents answered questions ~3.5s faster than competent respondents, and ~5s faster than beginner respondents (Table 4-13).

Table 4-13: Map expertise response time results for independent variable sub-categories.

	Parameter				95% Confidence Interval	
Variables	Estimate	Std. Error	t	Sig.	Lower	Upper
Intercept	18.236	1.910	9.546	.000	13.607	22.864
Map Expertise						
Beginner	5.063	1.734	2.919	.004 *	1.560	8.476
Competent	3.441	1.575	2.185	.030 *	.342	6.540
Proficient	–	–	–	–	–	–

Mean scores and confidence intervals also show that proficient respondents had faster response times, and beginner respondents had slower response times (Table 4-14).

Table 4-14: Map expertise response time results for independent variable sub-categories.

Variables	Mean	Std. Error	95% Confidence Interval Lower	Upper
Map Expertise				
Beginner	23.348	1.125	21.099	25.598
Competent	20.565	.966	18.614	22.516
Proficient	17.765	1.026	15.702	19.828

4.4 Basemap Preference Results

Descriptive statistics show that respondents liked street basemaps the most, and canvas basemaps the least (Table 4-15). Cronbach's alpha (α) indicated strong internal consistency measurements ($\alpha > 0.7$), meaning that basemap types were independently assessed. As a reminder, lower mean scores indicate greater respondent preferences.

Table 4-15: Basemap preference results.

Type	N of Items	Cronbach's α	Mean	Scaled Mean	Variance
Canvas	9	0.835	3.67	33.07	0.231
Street	9	0.720	2.53	22.82	0.236
Topographic	9	0.709	2.78	25.06	0.106

Respondents preferred street basemaps for seven of the nine geographic locations (Table 4-16). Topographic basemaps were favoured for the remaining two locations. Canvas basemaps were least preferred for all locations.

Table 4-16: Basemap preference results by geographic location.

Location	High Preference	Mid. Preference	Low Preference
Auckland	Street 2.09	Topographic 2.43	Canvas 2.96
Christchurch	Street 2.29	Topographic 2.52	Canvas 4.20
Fairlie	Street 2.53	Topographic 3.46	Canvas 4.26
Fiordland	Topographic 2.92	Street 3.56	Canvas 4.20
Huntly	Street 2.31	Topographic 2.84	Canvas 3.67
New Zealand	Street 2.46	Topographic 2.68	Canvas 3.66
Rotorua	Street 2.03	Topographic 2.45	Canvas 3.63
Thames	Street 2.50	Topographic 2.77	Canvas 3.07
Waikawa	Topographic 3.00	Street 3.05	Canvas 3.14

4.4.1 Basemap Preference Results: Map Expertise

Descriptive statistics show that all map expertise groups liked street basemaps the most, and canvas basemaps the least (Table 4-17). Cronbach's α indicated strong internal consistency measurements (α > 0.7) for all but two cases; however, as those cases' α scores were above 0.6, they were considered usable. As a reminder, lower mean scores indicate greater respondent preferences.

Table 4-17: Basemap preference results for map expertise groups.

Expertise	Basemap	N of Items	Cronbach's α	Mean	Scaled Mean	Variance
Beginner	*Canvas*	9	.829	3.745	33.702	.310
Beginner	*Street*	9	.724	2.471	22.243	.378
Beginner	*Topographic*	9	.622	2.832	25.486	.104
Competent	*Canvas*	9	.766	3.846	34.611	.228
Competent	*Street*	9	.668	2.529	22.759	.346
Competent	*Topographic*	9	.770	2.805	25.240	.172
Proficient	*Canvas*	9	.861	3.415	30.739	.214
Proficient	*Street*	9	.799	2.597	23.369	.117
Proficient	*Topographic*	9	.707	2.722	24.500	.117

Beginner and competent respondents preferred street basemaps for eight of the nine geographic locations (Table 4-18). Proficient respondents preferred topographic basemaps for four of the nine locations. The Fiordland basemap, which showed only natural features, was preferred as a topographic basemap by all map expertise groups.

Table 4-18: Basemap preference results for map expertise groups, by geographic location.

Location	High Preference	Mid. Preference	Low Preference
Auckland			
Beginner	Street 1.75	Topographic 2.54	Canvas 3.08
Competent	Street 2.00	Topographic 2.40	Canvas 3.12
Proficient	Topographic 2.36	Street 2.45	Canvas 2.67
Christchurch			
Beginner	Street 2.08	Topographic 2.70	Canvas 4.35
Competent	Street 2.22	Topographic 2.46	Canvas 4.35
Proficient	Topographic 2.43	Street 2.54	Canvas 3.91
Fairlie			
Beginner	Street 2.59	Topographic 3.27	Canvas 4.37
Competent	Street 2.51	Topographic 3.64	Canvas 4.50
Proficient	Street 2.47	Topographic 3.39	Canvas 3.89
Fiordland			
Beginner	Topographic 3.40	Street 3.83	Canvas 4.24
Competent	Topographic 2.88	Street 3.74	Canvas 4.35
Proficient	Topographic 2.56	Street 3.13	Canvas 3.97
Huntly			
Beginner	Street 2.32	Topographic 2.59	Canvas 3.70
Competent	Street 2.18	Topographic 2.85	Canvas 3.75
Proficient	Street 2.45	Topographic 3.02	Canvas 3.54
New Zealand			
Beginner	Street 2.72	Topographic 3.00	Canvas 3.97
Competent	Street 2.42	Topographic 2.62	Canvas 3.88
Proficient	Street 2.28	Topographic 2.47	Canvas 3.15
Rotorua			
Beginner	Street 2.02	Topographic 2.51	Canvas 3.83
Competent	Street 1.90	Topographic 2.35	Canvas 3.72
Proficient	Street 2.17	Topographic 2.50	Canvas 3.34
Thames			
Beginner	Street 2.13	Topographic 2.67	Canvas 2.91
Competent	Street 2.59	Topographic 2.81	Canvas 3.31
Proficient	Street 2.69	Topographic 2.78	Canvas 2.89
Waikawa			
Beginner	Street 2.75	Topographic 2.78	Canvas 3.21
Competent	Street 3.16	Topographic 3.18	Canvas 3.59
Proficient	Topographic 2.95	Street 3.15	Canvas 3.34

Chapter Summary

One-hundred and thirty-seven respondents completed the online survey. Statistical results indicated that basemap type did not significantly affect map usability for search and search-along-route map use tasks. Larger map scales significantly improved map reading effectiveness (accuracy scores), and map expertise significantly improved map reading efficiency (response times). Map complexity and map use tasks had no significant effect on respondents’ map reading performance.

Basemap preference results indicated that respondents liked street basemaps the most, and canvas basemaps the least. Basemap preferences were similar between map expertise groups, however, proficient respondents preferred the topographic basemaps for more geographic locations.

Chapter 5 - Discussion

The online survey results, presented in Chapter 5, examined how basemap type, map scale, map complexity, map use tasks, and map expertise affected respondents' map reading performance. In addition, respondents' basemap preferences were examined. All research questions can be answered using the found results.

This chapter discusses the online survey results in regard to the research questions introduced in Chapter 1 (pages 3-4). Each section reviews the results, makes comparisons to previous research and literature, addresses methodological limitations, and explains the importance of these findings. Basemap usability is discussed first, followed by map scale, map complexity, and map expertise. Next, basemap preferences are examined. The last section discusses how map reading performance and basemap preference may be related.

5.1 *How does basemap type affect map usability?*

Basemap type had no statistically significant effect on respondents' map reading performance. Specifically, no differences in accuracy scores or response times were observed between ESRI's canvas, topographic, and street basemap types. These results, however, are particular to the use of search and search-along-route map use tasks.

Although not statistically significant, results indicated that respondents were less accurate and had slower response times using street basemap types. Comparatively, respondents were more accurate and had faster response times using canvas basemap types. Statistical differences between the topographic and street basemap types were too small to make inferences. These findings suggest that canvas basemaps may improve map reading performance – when performing search-based tasks.

As usability comparisons of rendered basemaps are not well represented in the literature, results cannot be compared with previous findings. However, the results may be critiqued against the cartographic and usability literature. The literature asserts that basemaps can affect the map's functional success, and visual appeal (Imhof, 2007; Kraak & Ormeling, 2011; Robinson et al., 1995). Furthermore, previous basemap usability studies have found that the basemap can significantly affect map users' map reading performance (Dillemuth, 2005; Konečný et al., 2011; Phillips & Noyes, 1982).

The literature states that canvas basemaps can reduce visual distractions, and bring attention to thematic data (Akella & Field, 2011a; Akella & Yule, 2011). According to Akella and Field (2011b), canvas basemaps support a good visual hierarchy, allowing for thematic data to be perceived more effectively, and efficiently. In turn, the minimalistic design of canvas basemaps may explain why respondents were more accurate, and had faster response times. This research cannot, however, strongly support this claim with statistical results.

Several reasons may explain why no statistically significant differences in basemap usability were found. First, the survey maps were designed for search-based tasks, in particular, identifying thematic features on the map(s). Different thematic content was used to remove any familiarity effects between maps, and these features were designed to stand out from the basemap(s) (so that respondents could easily identify content referred to in the survey questions). As a result, good visual hierarchy was established for all survey maps.

Designing 'good' survey maps was intentional, however, it was not realized at the time how this may affect map reading results. Consequently, respondents' effectiveness and efficiency of successfully identifying thematic content may not have been challenged by the three basemap types. Using thematic content consistent across the survey maps, instead of varying content, could have potentially revealed different results.

Second, the context for using the survey maps was amiable; specifically, respondents were under no situational pressure, or time constraints, when using the map(s). The literature maintains that context plays an important role in the map's usability (Brown et al., 2013b; Harding et al., 2009; Nivala & Sarjakoski, 2003). According to Nivala and Sarjakoski (2003, p. 15), contextual design ensures that "the user has the right type of map, at a suitable scale and with the symbology adapted for the specific usage situation." As the survey imposed no contextual pressures on respondents, the basemaps may be considered appropriate for the survey's purpose, and respondents' needs. In turn, for the purposes of the survey, the three different basemap types all provided the appropriate contextual and geographic supporting information necessary to effectively and efficiently answer the survey questions.

Similarities in the basemaps' cartography may also explain why no statistically significant differences in basemap usability were observed. The canvas, topographic and street basemaps evaluated in this study – all designed by ESRI – shared similar symbologies, labels and visual variables. For instance, cartographic similarities in label hierarchy, feature contrasts, and types of features may be seen. Furthermore, these similarities exist despite changes in map scale, map complexity or geographic location. In consequence, the basemaps may have been too similar to one another for map reading performance to be significantly affected.

Overall, this research infers that basemap type may not significantly affect map usability for performing search and search-along-route map use tasks. This claim, however, is relative only to the basemaps evaluated within this study: ESRI's light grey canvas, topographic, and street basemaps. It is believed that the methodological design of this study, including a combination of the addressed survey limitations or errs, resulted in the observed basemap usability outcome. These results may offer further insight on basemap usability to researchers and map authors, which could be potentially valuable for improving how maps are designed, as well as enhancing the map users' experience.

5.2 *How does map scale affect map usability?*

Map scale had a statistically significant effect on respondents' map reading effectiveness (accuracy scores) when performing search and search-along-route tasks. Specifically, larger map scales improved respondents' accuracy scores. Response times were not significantly affected by changes in map scale.

According to the literature, the map's scale can affect how geographic space is utilized (Fabrikant, 2001; MacEachren, 1995; Roth et al., 2011). Larger map scales show more geographic detail and context across smaller geographic areas (Kraak & Ormeling, 2011; Krygier & Wood, 2011; Monmonier & Schnell, 1988). Respondents' map reading accuracy scores may have improved as a result of more detail being shown on the larger scale basemaps. Specifically, respondents may have been able to reference thematic content against the basemaps more effectively as a result of greater basemap detail.

Although not statistically significant, results indicated that respondents had slower response times using larger map scales, and faster response times using smaller map scales. The literature shows that too much information, or detail, may overwhelm map users with unnecessary information, and hinder usability (Fabrikant, 2001; MacEachren, 1995). For instance, Castner and Eastman (1985) found that more detailed (or complex) maps took more time for map users to process. Furthermore, previous basemap usability studies have found that satellite imagery basemaps, which show an enormous amount of geographic content, can hinder map usability (Dillemuth, 2005; Konečný et al., 2011). Presumably, respondents' map reading efficiency may have improved with smaller map scales as a result of less basemap information and detail being shown.

Comprehensively, the literature contends that neither map scale (large or small) is inherently more usable than the other (Goodchild & Quattrochi, 1997; Joao, 1998; Kimerling et al., 2012). Instead, many researchers advocate that the visualization of Geographic Information (GI) is more responsible for map usability than viewing scale and map extent alone (Fabrikant, 2001; Forrest, 1999; McMaster & Shea, 1992). However, this study did not quantitatively assess and compare GI between basemap types. Basemap GI was not compared because methodologies for quantitatively assessing and comparing GI were not identified in the literature.

Overall, this research infers that the map's scale can affect map usability based on how GI is represented at different scales on the map. More detailed GI may provide map users with more accurate geographic context, which may improve map reading effectiveness. However, more detailed GI may also overwhelm map users if too much information is shown, therein hindering the map's usability. In this regard, map authors should design their maps with a map scale that shows an optimal level of GI detail relevant to the map's purpose, and the map users' needs.

5.3 *How does map complexity affect map usability?*

Map complexity had no statistically significant effect on respondents' map reading performance for search and search-along-route tasks. Specifically, no significant differences in map reading effectiveness (accuracy scores) or efficiency (response times) were observed between low, medium, and high complexity maps.

While map complexity had no significant effect on map usability in this study, the literature suggests that map complexity may still affect map usability (Castner & Eastman, 1985; Edler et al., 2014; MacEachren, 1982). For instance, Ciolkosz-Styk and Styk (2013) maintain that too much complexity may make the map difficult to use. Furthermore, MacEachren (1982) found that map complexity had a curvilinear relationship with map communication, specifically, map communication improved with complexity, but only up to a certain extent specific to the map user(s).

While not statistically significant, results indicated that respondents had greater accuracy scores using lower complexity maps. Response time parameters suggested that response times were fastest for low complexity maps; however, response time descriptive statistics were too small between map complexities to make inferences. Interestingly, the slowest response times were associated with medium complexity maps, which may imply an issue with the map complexity measurements. These findings suggest that lower complexity maps may improve map usability for search-based map use tasks; however, these claims cannot be strongly supported by statistical results.

Several reasons may explain why map complexity had no statistically significant effect on map usability in this study. First, the methodology for measuring map complexity may not have properly assessed what constitutes 'complex map features'. This study used four criteria to measure map complexity: total features, feature representations, labels, and colour. However, these criteria may not have been aligned with respondents' perceptions of map complexity. For instance, the literature shows that map users' perceptions of complexity are subjective (Fairbairn, 2006; MacEachren, 1982; Wachowicz et al., 2008).

Second, increases in the map complexity criteria may not have been related with increases in map reading difficulty. For instance, colours have been shown to improve map usability (Brewer, 2004; Imhof, 2007). This study assumed that the map complexity criteria increased map complexity (as perceived by respondents'), therein making the survey maps more difficult to use. However, if several of the map complexity criteria had instead improved map usability, this could explain why no statistically significant effects were observed.

Finally, the thresholds used to quantitatively differentiate low, medium and high complexity maps may have been too small to impact results. Specifically, if differences in map complexity were not observed by respondents, they may not have affected respondents' map reading performance. These difficulties with both defining and measuring map complexity are referenced in the literature (Fairbairn, 2006; Harrie & Stigmar, 2010).

While this study found that map complexity did not significantly affect map usability, a combination of the addressed methodological issues may be responsible for the result. According to MacEachren (1982, p. 45), "it may be found that the influence of complexity on map effectiveness varies with the situation in which the map is used, or with different levels of training on the part of the map user". For this reason, map authors are recommended to design their maps with an optimal level of map complexity appropriate for the map's purpose, and the expected map reading abilities of the user(s).

5.4 *How does map expertise affect map reading performance?*

Statistical results found that map reading efficiency (response time) was significantly faster for respondents with more map expertise than respondents with less map expertise. Map expertise did not, however, significantly affect map reading effectiveness (accuracy scores). These findings suggest that mapping experience can significantly improve the speed at which map users' retrieve information from the map.

Similar studies have also found that map expertise improved map users' map reading efficiency (Anderson & Leinhardt, 2002; Konečný et al., 2011; Ooms et al., 2012).

According to Ooms et al. (2012), map users with more map expertise may interpret maps and GI faster because they have more experience recognizing and processing GI criteria. It is important to understand how map expertise may affect map reading efficiency because it can allow map authors to design maps based on the users' needs. For instance, specifying time durations for a map series animation, or designing maps for military or emergency situation personnel.

Map expertise did not significantly affect map reading effectiveness (accuracy scores) in this study. Several studies have also observed that map expertise did not necessarily improve map reading effectiveness (accuracy scores) (Deeb et al., 2014; Fabrikant, 2001; Gilhooly et al., 1988). For instance, Gilhooly et al. (1988) found that map expertise had no significant effect on map users' ability to read planimetric maps (i.e., maps showing only the x and y locations of features across horizontal distances). It may be that respondents' map reading abilities were not challenged enough by the survey maps, or map use tasks, to significantly affect map reading effectiveness.

The maps used in the online survey were designed for non-expert users (i.e., the maps did not require specialized knowledge or map reading experience for proper use). As a result, the survey maps were relatively simple, and basic (commonly used) thematic symbologies were used. According to Kulhavy and Stock (1996), novice and expert map users process basic map information identically. Moreover, search-based map use tasks are relatively easy to perform (McCann, 1982; van Elzakker, 2004). In consequence, the simplicity of the maps and map use tasks used in this study may not have challenged respondents' map reading abilities adequately enough for significant differences in map reading effectiveness to be observed.

This study determined that more map expertise can significantly improve map reading efficiency for search and search-along-route map use tasks. Comprehensively, researchers recommend that map authors consider the map users' background and expertise when designing the map (Foerster et al., 2012; Harding et al., 2009; MacEachren, 1995). For instance, if a map is intended for inexperienced users, its design should be simpler than a map intended for experienced users (Forrest, 1999). By understanding how map expertise may affect map usability, map authors can design their maps for the expected map reading abilities of the user(s). In turn, map usability may improve, and the user(s) may have a better experience with the map.

5.5 *Which basemap types do map users prefer?*

Survey respondents liked street basemaps the most, and canvas basemaps the least. Specifically, the street and topographic basemaps were favoured by respondents, whereas the canvas basemaps were generally disliked. Street basemaps were preferred for seven of the nine geographic locations; topographic basemaps were preferred for the remaining two locations (Fiordland, and Waikawa). Canvas basemaps were least preferred for all locations. These basemap preferences were seen across all map expertise groups; however, proficient respondents preferred the topographic basemaps for Auckland and Christchurch in addition to the two aforementioned topographic basemaps. These findings indicate that basemaps with more aesthetic properties are generally preferred by map users.

The basemap preference results indicated that respondents preferred basemaps with more: features, colours, labels, and relief visualization. The street and topographic basemaps featured more of these aesthetic properties than the canvas basemaps. Respondents' basemap preferences also indicated that respondents preferred basemaps with semantically correct colours (i.e., greens for vegetation, blues for water, etc.). The literature shows that colours and relief can improve the map's aesthetic appeal (Karssen, 1980; Keates, 1996; Tufte, 1989), and map users generally prefer maps with semantically correct colours (Fabrikant et al., 2012; Peterson, 2009). Furthermore, several researchers have observed an increase in user interest with more features (map complexity) (MacEachren, 1982; Ortag, 2009; Yarnal & Coulson, 2013). For instance, MacEachren (1982) observed that user interest increased with more feature classes.

The two topographic basemaps preferred by respondents were: Fiordland, and Waikawa. The Fiordland topographic basemap featured no man-made cultural features, but displayed contour lines, and several elevation points of interest. Comparatively, the Fiordland street and canvas basemaps showed only basic geographic information (i.e., basic geographic landscape, and several labels for the street basemap only). As a result, the topographic basemap provided more interesting geographic features and information for the Fiordland location, which may explain why the topographic basemap was preferred.

The Waikawa basemap had relatively few features, colour varieties, and labels. The topographic basemap for Waikawa, however, featured a green hue, whereas the street basemap did not. Furthermore, the Waikawa topographic basemap used a soft blue hue to visualize water, whereas the Waikawa street basemap used a grey-saturated blue. As results indicated, Waikawa was preferred as a topographic basemap. In turn, it can be presumed that more natural appearing colour hues are preferable to map users.

Relief is another aesthetic property favoured by many map users (Keates, 1996; Ortag, 2009). Both the topographic and street basemaps visualized relief, whereas the canvas basemaps did not. Interestingly, relief on the Fairlie topographic basemap was more generalized than relief on the Fairlie street basemap. Consequently, respondents preferred the street basemap more than the topographic basemap. These results imply that map users prefer basemaps with more relief visualization.

Respondents' may have preferred street basemaps overall as a result of more experience with, or exposure to, the street basemap style. Several researchers contend that map users prefer designs that are more familiar (Kong et al., 2015; Šavrič et al., 2015). According to Nielsen (2015), Google Maps (a street basemap design) was the sixth most popular mobile application in 2015. The Google Maps basemap is also common in many popular social media applications (O'Beirne, 2016). If survey respondents were more familiar with street basemap types, it may explain why respondent's preferred the street basemaps overall.

Comparing basemap preferences between map expertise groups revealed that proficient respondents preferred the topographic basemaps more than competent and beginner respondents. Topographic basemaps can require some level of knowledge of training to use properly (Kimerling et al., 2012; Kraak & Ormeling, 2011), and experienced map users are presumed to have more topographic basemap experience than inexperienced map users. The topographic basemaps may have been favoured by the proficient respondents because those respondents potentially had more experience with, or exposure to, topographic basemap types.

Overall, this study found that respondents preferred street basemaps over topographic and canvas basemap types. Topographic basemaps, however, were favoured when natural landscapes or more appealing aesthetic properties were shown. Canvas basemaps were disliked, presumably because they exhibited few aesthetic properties. It is important to understand map users' basemap preferences so that cartographic design principles can adhere to map users' aesthetic preferences, and map authors can select basemaps that are potentially more appealing to map users. With this knowledge, map authors may be able to design maps that are more functional, aesthetically appealing, and provide a better experience to the map user(s).

5.6 *How are map reading performance and basemap preference related?*

Survey respondents' preferred street basemaps over topographic and canvas basemaps. Essentially, maps with more aesthetic properties were more appealing to respondents. However, no statistically significant differences in map reading performance were observed for basemap type, and map complexity variables. As a result, this study cannot propose a strong correlation between respondents' map reading performance, and basemap preferences. Consequently, this research may only speculate how map reading performance and basemap preference are related.

The literature suggests a strong relationship between performance and preference (Kessell & Tversky, 2011; Nielsen & Levy, 1994; Wachowicz et al., 2008). Perceptions of usability are also strongly correlated to actual usability (Sonderegger & Sauer, 2010; Tractinsky et al., 2000; Tuch et al., 2012). For instance, Konečný et al. (2011) found that satellite imagery basemaps were more difficult to use, as well as less appealing to map users. Moreover, Dillemuth (2005) found that generalized (rendered) basemaps were easier to use, and more appealing to map users.

While street basemap types were preferred by survey respondents, the map reading results suggested that these basemaps were more difficult to use (although not statistically significant). Alternatively, respondents map reading effectiveness and efficiency slightly improved with canvas basemap types (again, not statistically significant). Accordingly, it may be presumed that the basemap types map users prefer are not necessarily the most usable. Other researchers have also claimed that the most popular basemap is not necessarily the most usable (Hu et al., 2015; Hunter et al., 2007).

The literature maintains that basemaps with subtle or neutral colours allow thematic features to be easily identified (Imhof, 2007; Peterson, 2009; Wesson & Glynn, 2013). In this sense, canvas and bespoke basemaps may improve usability when searching for thematic content. However, map users often favour maps that are more visually complex (Keates, 1996; Tufte, 1989; Yarnal & Coulson, 2013). Moreover, Ortag (2009) found that map users often evaluate the map's usability based on their aesthetic preferences. In this regard, map users' (and authors) may believe that the map (and basemap) is easy to use if it is more aesthetically appealing.

Based on the map reading and basemap preference results of the online survey, this study could not infer how map reading performance and basemap preference are related. It seems logical to assume that an aesthetically appealing map may provide more avenues for improved usability. However, considering the map's purpose and the map users' map reading abilities, a less appealing map may be more functionally usable, and more appropriate for certain situations. According to Phillips and Noyes (1982), optimal map usability is attained when the map contains as much information as possible without becoming illegible, unattractive or unusable. In consequence, the usability of the map may improve when an appropriate balance between functional design and aesthetic appeal is considered by the map author.

Chapter 6 - Conclusion

Basemaps are a fundamental component of most maps, and may affect the map's functional success and visual appeal (Imhof, 2007; Kraak & Ormeling, 2011; Robinson et al., 1995). The literature contends that an optimal basemap provides geographic and contextual reference for thematic data, and the appropriate Geographic Information (GI) and contextual design necessary for the map users' needs (Harding et al., 2009; Nivala & Sarjakoski, 2003; Robinson et al., 1995). Current basemap selection guidelines also recommend that map authors select a basemap in line with the map's intended topic, scale, purpose, context of use and audience (Harding et al., 2009; Kraak & Ormeling, 2011; Robinson et al., 1995). Basemap aesthetics are also considered important, as the map's marketable success may rest on its ability to attract users (Brewer, 2004; Imhof, 2007; Ortag, 2009).

Basemap usability research can potentially improve users' experiences with the map. Previous studies have found significant differences in map usability when comparing satellite/aerial imagery basemaps with rendered basemaps (Konečný et al., 2011; Dillemuth, 2005). Moreover, previous cartographic comparisons of basemaps have put forward suggests for the appropriateness of different basemap types based on the map users' needs (O'Beirne, 2016).

This study designed an online survey to evaluate basemap usability. The survey found no statistically significant differences in usability between ESRI's canvas, topographic, and street basemap types for search and search-along-route tasks. Based on these findings, map authors may select any of the three studied basemap types for the map (when used for search or search-along-route purposes), without significantly compromising usability.

Map scale, map complexity, map expertise, and basemap preference were also examined in this study. Map scale had a statistically significant effect on respondents' map reading effectiveness. Specifically, larger map scales improved map reading accuracy scores. After discussing the survey results, it was suggested that map authors design their maps with a map scale appropriate for visualizing GI at an optimal level of detail relevant to the map users' needs.

Map complexity had no statistically significant effect on survey respondents' map reading performance. Specifically, results found no statistically significant differences in respondents' map reading effectiveness or efficiency between low, medium, and high complexity maps. Following a discussion of the effects of map complexity, it was presumed that the methodological design may have been responsible for this outcome. Based on these findings, it was suggested that map authors design their maps with an optimal level of map complexity appropriate for the map's purpose, and the map reading abilities of the user(s).

Survey respondents' mapping expertise was measured and compared for differences in map reading performance, and basemap preference. Respondents were categorized into beginner, competent, and proficient map expertise categories. Comparing map reading performance results between the three map expertise groups revealed that map reading efficiency was significantly faster for respondents with more map expertise. Map expertise did not, however, significantly affect respondents' map reading effectiveness.

When inquired about their subjective preferences for ESRI's street, topographic, and canvas basemaps, respondents' liked street basemaps the most, and canvas basemaps the least. Specifically, street and topographic basemaps were favoured by respondents, whereas canvas basemaps were generally disliked. These preferences were generally observed across different geographic locations, and map expertise groups.

Based on the findings of this study, speculations were made on how map reading performance and basemap preference are related. From a discussion considering the survey results and claims made in the scientific literature, it was assumed that an aesthetically appealing map may provide more avenues for improved usability. However, based on the map's purpose, and the map users' map reading abilities, a less appealing map could be more functionally usable, and more appropriate for certain situations.

6.1 Future Research Directions

Basemap usability research may be extended beyond the limitations of this study in the following ways. First, basemap usability was not compared for different contextual uses (i.e., different situations or scenarios in which basemaps are used). Contextual basemap usability testing could potentially identify which types of basemaps may be more appropriate for different map use scenarios, or user groups. As a result, future studies could test the usability of basemaps more appropriately by comparing their usability under different situational, and usage contexts.

Basemap cartography was also not evaluated in this study. Future studies can investigate how differences in basemap GI may affect map usability further, specifically, how aesthetic and/or visual variables may affect basemap usability. More research could also be done examining and comparing map users' basemap preferences.

Finally, opportunities are available for future studies to investigate how map reading performance may be related to map users' basemap preferences. Investigating this relationship further may provide valuable insight on how maps and GI can be optimally designed for different map purposes, and map users' needs. These areas of basemap usability may provide researchers, and map authors, with valuable information relating to how maps work, and how they are experienced by map users.

6.2 Concluding Statements

The basemap can affect the usability of the map. An appropriate basemap may improve map usability, whereas an inappropriate basemap may hinder map usability. This study aspires to bring points of consideration to map authors regarding what constitutes an optimal basemap type for the map's purpose, and the map users' needs – therein improving the usability of the map.

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Appendix A: Demographic Survey Questions

1) What is your gender?
   - Male
   - Female

2) What age category do you belong to?
   - Under 16
   - 16 – 20
   - 20 – 29
   - 30 – 39
   - 40 – 49
   - 50 – 59
   - 60 or older

3) What is the highest degree or level of education you have completed?
   - No schooling completed
   - Primary School
   - High School
   - Trade / Technical / Vocational Training
   - Associate Degree
   - Bachelor's Degree
   - Postgraduate Diploma / Master's Degree
   - Doctorate Degree
   - Other (please specify) [ ]

4) Which country do you currently live in? [ ]

Appendix B: Map Expertise Survey Questions

1) In terms of your expertise using maps, are you a…

   - Novice
   - Beginner
   - Competent
   - Proficient
   - Expert

2) How often do you use maps?

   - Never
   - A few times a year
   - A few times a month
   - A few times a week
   - Every day

3) Have you ever received training to use maps?

   - Yes, please specify (example: through work, education, etc.) ________
   - No

4) Have you ever received training to create maps?

   - Yes, please specify (example: through work, education, etc.) ________
   - No

5) Have you ever assisted in the creation of a digital basemap?

   - Yes, within the last 3 years
   - Yes, more than 3 years ago
   - No
   - I'm unsure what a basemap is.

6) Have you ever created a map on the internet?

   - Yes, within the past 6 months
   - Yes, within the past year
   - Yes, more than a year ago
   - No

7) Which of these types of maps have you used within the past month?
Select all that apply.

- ☐ Online maps (Google Maps, Bing Maps, OpenStreetMap, etc.)
- ☐ Mapping application on mobile device
- ☐ Vehicle Navigation System
- ☐ Road Atlas
- ☐ World Map
- ☐ Topographic Map
- ☐ World Atlas
- ☐ Other, please specify ____________
- ☐ None

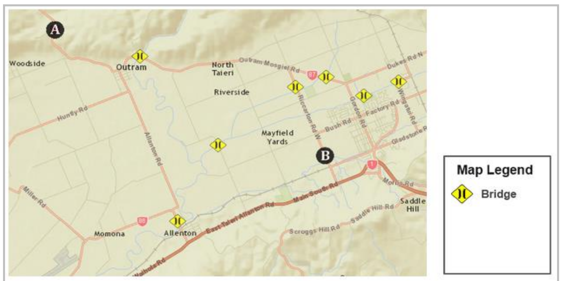
Appendix C: Map Reading Survey Questions and Maps

How many train stations are located along the railway line between points A and B?

- ○ 0
- ○ 1
- ○ 3
- ○ 5
- ○ Unsure

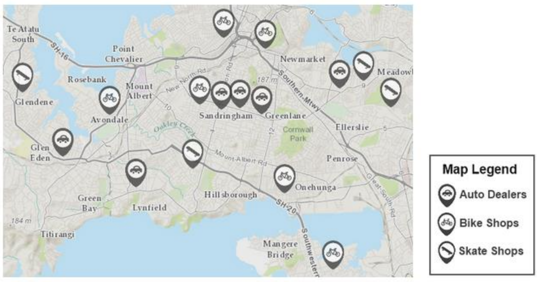
How many nature trails west of Katikati have vehicle parking zones?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ Unsure



Travelling from point A to point B along the major roadways and passing through North Taieri, how many bridges will you cross?

- ○ 0
- ○ 2
- ○ 5
- ○ 7
- ○ Unsure

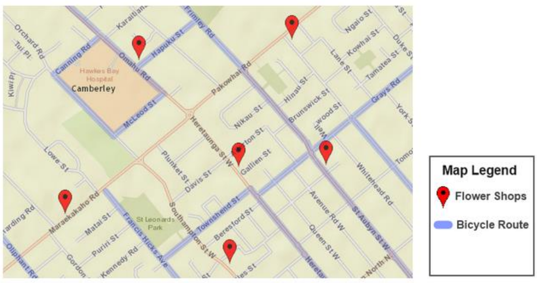


How many auto dealerships are located in Penrose?

- ○ 0
- ○ 1
- ○ 3
- ○ 5
- ○ Unsure

How many campsites are located south of the Ashley River?

- ○ 0
- ○ 1
- ○ 2
- ○ 5
- ○ Unsure

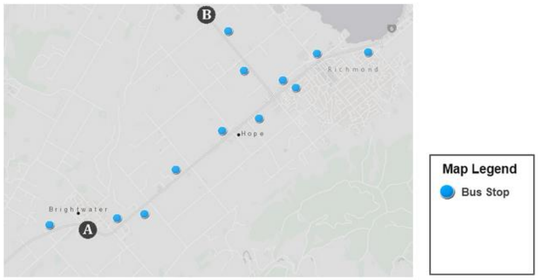


How many flower shops are located along bicycle routes?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ Unsure

How many farm and livestock paddocks are located north of State Highway 2?

- ◯ 0
- ◯ 2
- ◯ 3
- ◯ 5
- ◯ Unsure



How many total bus stops are located on the highway between points A and B?

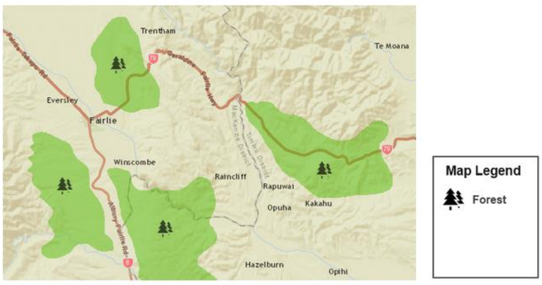
- ◯ 0
- ◯ 3
- ◯ 5
- ◯ 7
- ◯ Unsure

How many traffic accidents have been reported between Wharewaka and Hatepe?

- ◯ 0
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ Unsure

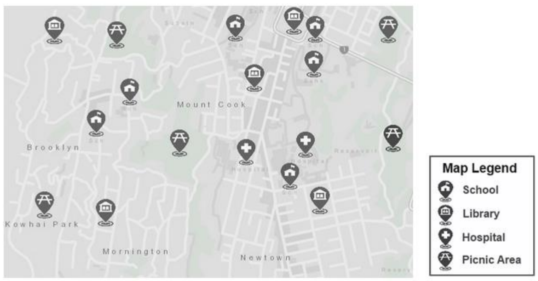
How many hotels are located between Wanaka Golf Course and the Information Centre?

- ◯ 0
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ Unsure



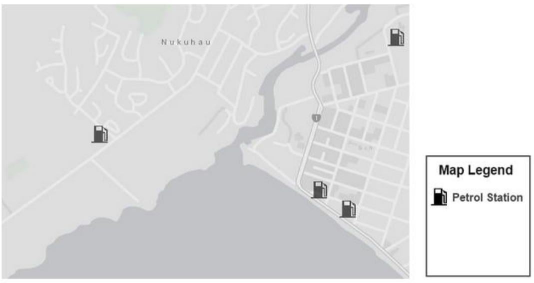
How many conifer forests will you pass through travelling along Highway 79 from Fairlie?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 4
- ◯ Unsure



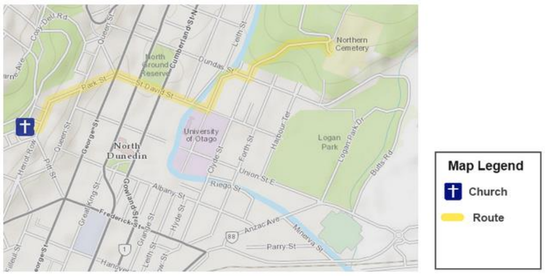
How many hospitals are located in Brooklyn?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 5
- ◯ Unsure



How many petrol stations are located within 3 blocks of State Highway 1?

- ○ 0
- ○ 2
- ○ 3
- ○ 4
- ○ Unsure

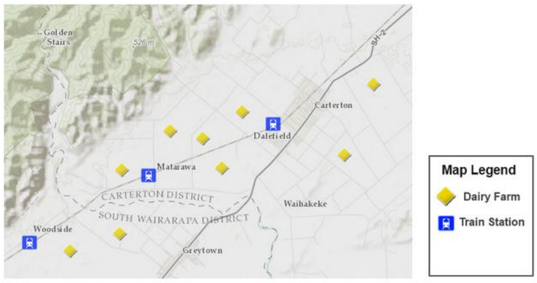


Following the highlighted funeral procession route from the church to the northern cemetary, how many major roadways does the route cross?

- ○ 0
- ○ 2
- ○ 3
- ○ 5
- ○ Unsure

How many times do mountain bike paths cross the river?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ Unsure



How many dairy farms are visible out the left side of the train traveling from Woodside to Dalefield?

- ○ 0
- ○ 3
- ○ 4
- ○ 5
- ○ Unsure

How many restaurants are located in St Albans?

- ○ 0
- ○ 2
- ○ 3
- ○ 5
- ○ Unsure

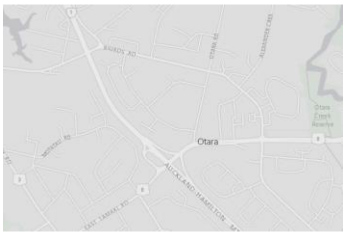
Following the highlighted route from point A to B, once south of Moorhouse Ave how many wifi zones will you pass through?

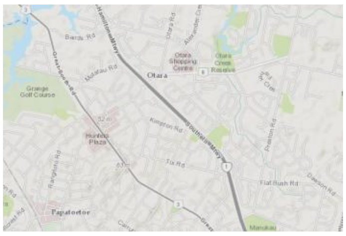
- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ Unsure

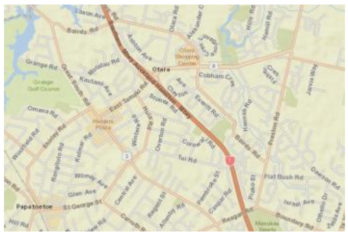
Appendix D: Basemap Preference Maps

Canvas	*Topographic*	*Street*

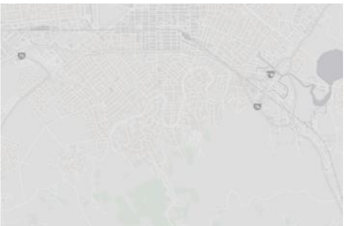
Auckland

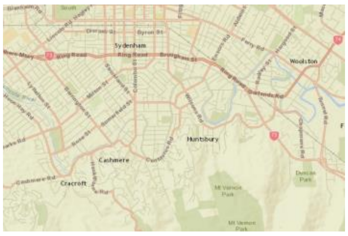






Christchurch



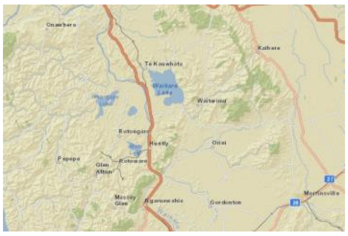
Fairlie



Fiordland



Huntly

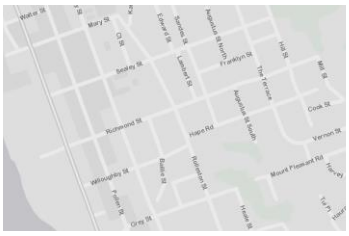
New Zealand

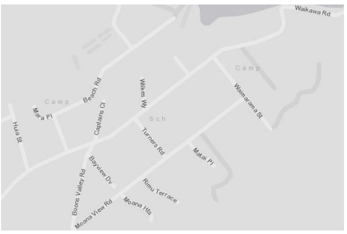
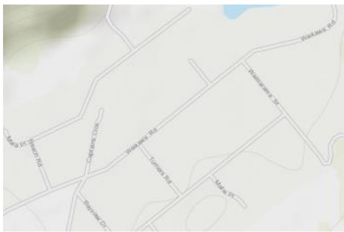
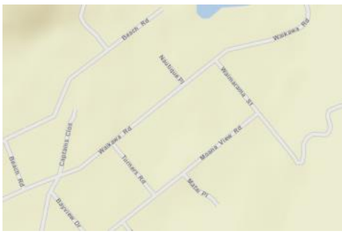
Rotorua

Thames

Waikawa

Appendix E: Map Reading Statistical Results

E-1: Map expertise accuracy results for independent variable sub-categories.

Variables	Contrast Estimate	Std. Error	Sig.	95% Confidence Interval Lower	Upper
Map Expertise					
Beginner vs Competent	.015	.015	.320	-.015	.045
Beginner vs Proficient	.014	.016	.372	-.017	.045
Competent vs Proficient	-.001	.012	.933	-.025	.023

E-2: Map expertise accuracy results for independent variable sub-categories.

Variables	Mean	Std. Error	95% Confidence Interval Lower	Upper
Map Expertise				
Beginner	.077	.025	.040	.143
Competent	.062	.019	.034	.113
Proficient	.064	.019	.035	.114

E-3: Accuracy results for independent variable sub-category interactions.

Pairwise Contrasts		Contrast Est.	Std. Error	Sig.	95% Confidence Interval Lower	Upper
Basemap Type	*Map Complexity*					
Canvas vs Topographic	High	-.032	.054	.553	-.138	.074
Canvas vs Street	High	-.026	.051	.608	-.126	.074
Topographic vs Street	High	.006	.059	.919	-.109	.121
Canvas vs Topographic	Medium	-.026	.099	.794	-.221	.169
Canvas vs Street	Medium	.059	.067	.384	-.073	.191
Topographic vs Street	Medium	.085	.082	.300	-.075	.245
Canvas vs Topographic	Low	.109	.116	.348	-.118	.336
Canvas vs Street	Low	.058	.145	.691	-.227	.342
Topographic vs Street	Low	-.051	.108	.638	-.264	.162
Basemap Type	*Map Scale*					
Canvas vs Topographic	Large	.229	.184	.214	-.132	.589
Canvas vs Street	Large	.243	.189	.200	-.128	.614
Topographic vs Street	Large	.014	.105	.890	-.191	.219
Canvas vs Topographic	Small	-.034	.034	.324	-.101	.033
Canvas vs Street	Small	-.018	.025	.480	-.066	.031
Topographic vs Street	Small	.016	.035	.646	-.053	.085
Basemap Type	*Map Use Task*					
Canvas vs Topographic	Search	-.065	.056	.246	-.174	.045
Canvas vs Street	Search	-.031	.040	.433	-.109	.047
Topographic vs Street	Search	.033	.061	.582	-.086	.152
Canvas vs Topographic	Search-Along-Route	.184	.137	.180	-.085	.452
Canvas vs Street	Search-Along-Route	.187	.137	.172	-.081	.455
Topographic vs Street	Search-Along-Route	.003	.057	.955	-.108	.114

E-4: Accuracy results for independent variable sub-category interactions.

Interacting Variables		Mean	Std. Error	95% Confidence Interval Lower	Upper
Basemap Type	*Map Complexity*				
Canvas	Low	.169	.107	.043	.477
Canvas	Medium	.088	.063	.020	.311
Canvas	High	.026	.032	.002	.244
Topographic	Low	.060	.046	.013	.237
Topographic	Medium	.114	.078	.027	.371
Topographic	High	.058	.044	.013	.229
Street	Low	.111	.099	.017	.473
Street	Medium	.029	.025	.005	.143
Street	High	.052	.040	.011	.211
Basemap Type	*Map Scale*				
Canvas	Large	.345	.173	.105	.702
Canvas	Small	.012	.016	.001	.153
Topographic	Large	.117	.068	.035	.324
Topographic	Small	.046	.030	.012	.156
Street	Large	.102	.081	.020	.392
Street	Small	.030	.019	.008	.100
Basemap Type	*Map Use Task*				
Canvas	Search	.019	.022	.002	.163
Canvas	Search-Along-Route	.249	.132	.077	.569
Topographic	Search	.084	.051	.024	.254
Topographic	Search-Along-Route	.065	.041	.018	.207
Street	Search	.050	.033	.013	.173
Street	Search-Along-Route	.062	.040	.017	.204

E-5: Map expertise accuracy results for independent variable sub-category interactions.

Pairwise Contrasts		Contrast Est.	Std. Error	Sig.	95% Confidence Intervals Lower	Upper
Basemap Type	*Map Expertise*					
Canvas	Beginner vs Competent	.022	.025	.388	-.027	.070
Canvas	Beginner vs Proficient	.020	.025	.439	-.030	.070
Canvas	Competent vs Proficient	-.002	.019	.925	-.039	.036
Topographic	Beginner vs Competent	.001	.025	.955	-.048	.051
Topographic	Beginner vs Proficient	.005	.026	.848	-.046	.055
Topographic	Competent vs Proficient	.004	.023	.877	-.041	.048
Street	Beginner vs Competent	.020	.024	.404	-.027	.068
Street	Beginner vs Proficient	.017	.025	.500	-.032	.065
Street	Competent vs Proficient	-.004	.019	.849	-.041	.034
Map Complexity	*Map Expertise*					
Low	Beginner vs Competent	.069	.042	.098	-.013	.152
Low	Beginner vs Proficient	.055	.040	.172	-.024	.133
Low	Competent vs Proficient	-.015	.026	.568	-.065	.036
Medium	Beginner vs Competent	-.008	.025	.761	-.056	.041
Medium	Beginner vs Proficient	.028	.026	.275	-.022	.078
Medium	Competent vs Proficient	.035	.025	.761	-.041	.056
High	Beginner vs Competent	.003	.017	.839	-.030	.036
High	Beginner vs Proficient	-.016	.020	.405	-.055	.022
High	Competent vs Proficient	-.020	.019	.304	-.058	.018
Map Scale	*Map Expertise*					
Large	Beginner vs Competent	.038	.041	.348	-.042	.118
Large	Beginner vs Proficient	.027	.042	.521	-.055	.108
Large	Competent vs Proficient	-.012	.034	.732	-.078	.055
Small	Beginner vs Competent	.005	.011	.662	-.017	.027
Small	Beginner vs Proficient	.006	.011	.578	-.016	.028
Small	Competent vs Proficient	.001	.009	.889	-.016	.019
Map Use Task	*Map Expertise*					
Search	Beginner vs Competent	.021	.019	.267	-.016	.059
Search	Beginner vs Proficient	.006	.017	.716	-.028	.041
Search	Competent vs Proficient	-.015	.014	.302	-.043	.013
Search-Along-Route	Beginner vs Competent	-.006	.028	.829	-.061	.049
Search-Along-Route	Beginner vs Proficient	.026	.029	.369	-.031	.082
Search-Along-Route	Competent vs Proficient	.032	.027	.230	-.020	.084

E-6: Map expertise accuracy results for independent variable sub-category interactions.

Interacting Variables		Mean	Std. Error	95% Confidence Interval Lower	Upper
Basemap Type	*Map Expertise*				
Canvas	Beginner	.089	.049	.029	.243
Canvas	Competent	.067	.037	.022	.188
Canvas	Proficient	.069	.038	.023	.192
Topographic	Beginner	.076	.037	.028	.189
Topographic	Competent	.075	.035	.029	.177
Topographic	Proficient	.071	.033	.028	.170
Street	Beginner	.069	.036	.024	.184
Street	Competent	.048	.026	.017	.131
Street	Proficient	.052	.027	.018	.140
Map Complexity	*Map Expertise*				
Low	Beginner	.150	.069	.057	.338
Low	Competent	.080	.040	.029	.201
Low	Proficient	.095	.046	.035	.230
Medium	Beginner	0.76	.038	.028	.190
Medium	Competent	.083	.038	.033	.195
Medium	Proficient	.048	.024	.017	.124
High	Beginner	.040	.025	.011	.128
High	Competent	.036	.022	.011	.115
High	Proficient	.056	.031	.018	.160
Map Scale	*Map Expertise*				
Large	Beginner	.189	.076	.081	.381
Large	Competent	.150	.061	.065	.311
Large	Proficient	.162	.064	.071	.328
Small	Beginner	.029	.018	.009	.094
Small	Competent	.024	.014	.008	.076
Small	Proficient	.023	.014	.007	.071
Map Use Task	*Map Expertise*				
Search	Beginner	.054	.029	.018	.148
Search	Competent	.033	.018	.011	.092
Search	Proficient	.047	.024	.017	.124
Search-Along-Route	Beginner	.110	.045	.048	.234
Search-Along-Route	Competent	.116	.044	.054	.234
Search-Along-Route	Proficient	.085	.034	.038	.179

E-7: Map expertise response time results for independent variable sub-category interactions.

Variable Interactions		Parameter Estimate	Std. Error	t	Sig.	95% Confidence Interval Lower	Upper
Intercept		18.236	1.910	9.546	.000	13.607	22.864
Basemap Type	*Map Expertise*						
Canvas	Beginner	1.146	1.102	1.040	.299	-1.015	3.308
Canvas	Competent	.490	.999	.491	.623	-1.468	2.450
Canvas	Proficient	–	–	–	–	–	–
Topographic	Beginner	–	–	–	–	–	–
Topographic	Competent	–	–	–	–	–	–
Topographic	Proficient	–	–	–	–	–	–
Street	Beginner	2.009	1.097	1.830	.067	-1.436	4.161
Street	Competent	.179	.994	.181	.857	-1.769	2.128
Street	Proficient	–	–	–	–	–	–
Map Complexity	*Map Expertise*						
Low	Beginner	.026	1.102	.024	.981	-2.135	2.188
Low	Competent	-.751	.997	-.753	.451	-2.708	1.205
Low	Proficient	–	–	–	–	–	–
Medium	Beginner	–	–	–	–	–	–
Medium	Competent	–	–	–	–	–	–
Medium	Proficient	–	–	–	–	–	–
High	Beginner	.189	1.098	.172	.863	-1.965	2.343
High	Competent	-1.305	.993	-1.304	.189	-3.252	.642
High	Proficient	–	–	–	–	–	–
Map Scale	*Map Expertise*						
Large	Beginner	.407	1.028	.396	.692	-1.610	2.425
Large	Competent	.334	.933	.358	.720	-1.496	2.165
Large	Proficient	–	–	–	–	–	–
Small	Beginner	–	–	–	–	–	–
Small	Competent	–	–	–	–	–	–
Small	Proficient	–	–	–	–	–	–
Map Use Task	*Map Expertise*						
Search	Beginner	-1.614	.949	-1.700	.089	-3.477	.248
Search	Competent	-.694	.857	-.809	.418	-2.376	.987
Search	Proficient	–	–	–	–	–	–
Search-Along-Route	Beginner	–	–	–	–	–	–
Search-Along-Route	Competent	–	–	–	–	–	–
Search-Along-Route	Proficient	–	–	–	–	–	–

E-8: Map expertise response time results for independent variable sub-category interactions.

Variable Interactions		Mean	Std. Error	95% Confidence Interval Lower	Upper
Basemap Type	*Map Expertise*				
Canvas	Beginner	23.102	1.433	20.082	26.123
Canvas	Competent	20.492	1.283	17.677	23.307
Canvas	Proficient	17.425	1.338	14.541	20.309
Street	Beginner	24.444	1.368	21.615	27.273
Street	Competent	20.659	1.208	18.076	23.242
Street	Proficient	17.904	1.263	15.240	20.567
Topographic	Beginner	24.499	1.325	19.781	25.216
Topographic	Competent	20.543	1.163	18.086	23.000
Topographic	Proficient	17.967	1.224	15.417	20.517
Map Complexity	*Map Expertise*				
Low	Beginner	22.782	1.368	19.953	25.611
Low	Competent	19.978	1.209	17.394	22.562
Low	Proficient	17.244	1.265	14.579	19.910
Medium	Beginner	25.114	1.328	22.391	27.837
Medium	Competent	23.088	1.165	20.629	25.547
Medium	Proficient	19.602	1.223	17.053	22.152
High	Beginner	22.149	1.429	19.135	25.164
High	Competent	18.628	1.278	15.819	21.438
High	Proficient	16.449	1.336	13.567	19.330
Map Scale	*Map Expertise*				
Large	Beginner	24.607	1.302	21.933	27.281
Large	Competent	21.787	1.147	19.363	24.211
Large	Proficient	18.820	1.203	16.309	21.331
Small	Beginner	22.090	1.393	19.152	25.027
Small	Competent	19.343	1.248	16.602	22.083
Small	Proficient	16.710	1.303	13.901	19.519
Map Use Task	*Map Expertise*				
Search	Beginner	21.185	1.341	18.390	23.980
Search	Competent	18.861	1.193	16.285	21.438
Search	Proficient	16.409	1.249	13.755	19.063
Search-Along-Route	Beginner	25.512	1.247	22.980	28.043
Search-Along-Route	Competent	22.268	1.086	20.014	24.522
Search-Along-Route	Proficient	19.121	1.145	16.769	21.474