Understanding and Supporting Cross-modal Collaborative Information Seeking

Al-Thani, Dena Ahmed S

Understanding and Supporting Cross-modal Collaborative Information Seeking

Dena Ahmed S Al-Thani

Submitted in partial fulfilment of the requirements of the

Degree of Doctor of Philosophy

School of Electronic Engineering and Computer Science

Queen Mary, University of London

February 24, 2016

Statement of Originality

I, Dena Ahmed S Al-Thani, confirm that the research included within this thesis is my own work or that where it has been carried out in collaboration with, or supported by others, that this is duly acknowledged below and my contribution indicated. Previously published material is also acknowledged below.

I attest that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge break any UK law, infringe any third party's copyright or other Intellectual Property Right, or contain any confidential material.

I accept that the College has the right to use plagiarism detection software to check the electronic version of the thesis.

I confirm that this thesis has not been previously submitted for the award of a degree by this or any other university.

Signature:

Date:

عَنْ أَبِي هُرَيْرَةَ ، عَنْ رَسُولِ اللَّهِ صَلَّى اللَّهُ عَلَيْهِ وَسَلَّمَ ، قَالَ : " إِذَا مَاتَ ابْنُ آدَمَ انْقَطَعَ عَمَلُهُ إِلا مِنْ ثَلاثٍ : مِنْ صَدَقَةٍ جَارِيَةٍ ،
أَوْ عِلْمٍ يُنْتَفَعُ بِهِ ، أَوْ وَلَدٍ صَالِحٍ يَدْعُو لَهُ".

The Messenger of Allah (ﷺ) said, "When a man dies, his deeds come to an end except for three things: Sadaqah Jariyah (ceaseless charity); knowledge which is beneficial; or a virtuous descendant who prays for him (the deceased)."

The aim of this PhD research is to make beneficial contributions to the body of HCI knowledge.

Acknowledgments

First and foremost, I would like to thank God (Allah) the almighty for the blessing of life.

Many thanks to my supervisor Dr. Tony Stockman for his constant help in providing guidance, research resources, encouragement, motivation and valuable feedback over the last four years. I first met Dr Stockman during my Masters course in 2008, when he first introduced me to the area of cross-modal interaction. Now, eight years later, I am incredibly glad to have reached this stage together. It has been a real pleasure working with such an inspiring scientist that I have learn a lot from both professionally and personally.

I would like to thank my second supervisor Dr. Tassos Tombros for always being available for advice on issues raised during our research. I am also very thankful for the careful reading and constructive comments that I received from my examiners, Dr. David Sloan and Dr. Mick Grierson. I would like to extend my thanks to my colleagues at the Cognitive Science Research Group for their highly valuable feedback.

I gratefully acknowledge all the participants that took part in the studies conducted. Their dedication and commitment has had a huge impact on the quality of work produced in this research. I am also hugely appreciative of the incredible support shown by my eldest sister Shuaa during the data-gathering stage of study 2, and in helping to proof-read the final draft.

A lot of love to my beautiful parents for all their support throughout my life, and for never letting me down. There are simply no words that can express how grateful I am for your endless love. Your prayer for me is what has sustained me thus far. I would like to express my love and appreciation for my brothers, sisters, nephews and nieces for simply always being there for me. And to my friends, managing always to be in touch despite the distance over all these years: your friendship means the world to me.

Abstract

Most previous studies of users with visual impairments (VI) access to the web have focused solely on single user human-web interaction. This thesis explores the under investigated area of cross-modal collaborative information seeking (CCIS), that is the challenges and opportunities that exist in supporting visually impaired users to take an effective part in collaborative web search tasks with sighted peers. The thesis examines the overall question of what happens currently when people perform CCIS, and how might the CCIS process be improved?

To motivate the work, we conducted a survey, the results of which showed that a significant amount of CCIS activity goes on. An exploratory study was conducted to investigate the challenges faced and behaviour patterns that occur when people perform CCIS. We observed 14 pairs of VI and sighted users in both co-located and distributed settings. In this study participants used their tools of choice, that is the web browser, note taker and preferred communications system. The study examines how concepts from the "mainstream" collaborative Information Seeking (CIS) literature, play out in the context of cross-modality. Based on the findings of this study, we produced design recommendations for features that can better support cross-modal collaborative search.

Following this, we surveyed mainstream CIS systems and selected the most accessible software package that satisfied the design recommendations from the initial study. Due to the fact that the software was not built with accessibility in mind, we developed JAWS scripts and employed other JAWS features to improve its accessibility and VI user experience. We then performed a second study, using the same participants undertaking search tasks of a similar complexity as before, but this time using the CIS system. The aim of this study was to explore the impact on the CCIS process when introducing a mainstream CIS system, enhanced for accessibility. In this study we looked into CCIS from two perspectives: the collaboration and the individual interaction with the interface. The findings from this study provide an understanding of the process of CCIS when using a system that supports it. These findings assisted us in formulating a set of guidelines toward supporting collaborative search in a cross-modal context.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

VI	Visually impaired
IS	Information Seeking
CIS	Collaborative Information Seeking
CCIS	Cross-modal Collaborative Information Seeking
PIM	Personal Information Management
IR	Information Retrieval
HCI	Human-Computer Interaction
CSCW	Computer Supported Cooperative Work
UI	User Interface
GUI	Graphical User Interfaces
IE	Internet Explorer
W3C	World Wide Web Consortium
WCAG	Web Content Accessibility Guidelines
WAI-ARIA	Web Accessibility Initiative - Accessible Rich Internet Applications
RQ	Research Question
JAWS	Job Access With Speech Screen reader
ACSZ	Accessible Collaborative Searching Zakta
VP	Visually Impaired Participant
SP	Sighted Participant
SD	Standard Deviation
T	t-test
$\chi 2$	Chi-square test

Chapter 1 Introduction

1.1 Introduction

Collaboration is a natural form of human behaviour that frequently occurs in social and professional settings. Numerous situations can trigger collaborative behaviour, and in some circumstances collaboration is an absolute necessity for a task to be completed (Denning and Yaholkovsky, 2008). Collaboration can sometimes be a requirement of a higher authority; for instance, a group of students are instructed to work together on a school project. In other situations, it can be a result of a shared or common need between a group of people and, in some situations, it is simply the need to have diverse skills across a group (Shah, 2010b).

In the context of Information Seeking (IS), collaboration has long been an important aspect of the process, either explicitly or implicitly (Twidale et al., 1997). People tend to collaborate when searching for information even if they were not explicitly asked to collaborate (Large et al., 2002; Morris, 2008). This collaboration can occur in educational settings (Foster, 2009) in the workplace (Morris, 2008) or even nowadays on social media platforms (Hecht et al., 2012). Collaboration involves a group of people searching with a shared information need. This process is commonly referred to as Collaborative Information Seeking (CIS) and it is defined as "activities that a group or team of people undertake to identify and resolve a shared information need" (Poltrock et al. 2003). Recent research about CIS has aimed at providing solutions and frameworks to support it (Golovchinsky et al., 2009; Morris and Teevan, 2010). The goal has been to enhance the productivity of the CIS process by increasing the coverage of the relevant information space, avoiding redundant work and providing several advantages over individual search interfaces. However the work in this field to date has always assumed that information seekers engaged in CIS are using the same access modality, the visual modality. The almost exclusive focus on this modality has failed to address the needs of users who employ different access modalities, such as haptic and/or audio. Visually Impaired (VI) employees in educational settings or workplaces may often have to collaborate with sighted team members when searching the web. VI search behaviour is challenged by substantial issues imposed by the current state of assistive technology (Stockman and Metatla, 2008; Sahib et al., 2012), so engaging in a web search activity with peers is a major barrier to workplace collaboration. The technologies available today for VI users to access the web impose numerous barriers (Brown et al., 2012). These barriers can hinder VI users working within a team and hence affect their overall inclusion and/or performance. Potentially this can negatively impact the integration of VI individuals in educational and workplace environments. The Royal National Institute of Blind People (RNIB) 2015 labour force survey estimated that (66.1%) of VI people within the UK are unemployed (Hewett, 2015).

Therefore, this thesis focuses on understanding the activity of collaborative information seeking between VI and sighted users, and it investigates approaches to support it. We refer to this activity as Cross-Modal Collaborative Information Seeking (CCIS). It is important to assert here that this thesis is not primarily concerned with web accessibility; rather it focuses on users' cross-modal collaborative behaviour and interaction. Nevertheless, web accessibility issues cannot of course be entirely excluded, as they can illuminate underlying problems affecting the ability to successfully perform CCIS.

This thesis employs a semi-structured approach that comprises a number of qualitative and quantitative research methods. We start by conducting a survey to find out if CCIS activity actually happens, which determines the relevance and feasibility of the work. This allows us to begin to develop an understanding of the CCIS process and its prevalence. We then conducted an observational study to deepen our understanding of the CCIS process and identify associated challenges. The knowledge gained from the survey and observational study enabled us to identify features and components that should be present in systems intended to support the CCIS process. Because there are numerous ways in which these features and components might be implemented, we proposed the investigation of these as forming an agenda for CCIS research.

After surveying the CIS field, we identified an existing CIS system which, with some additional enhancements to improve accessibility, enabled us to continue our investigation. After implementing some of these enhancements, we used the system to perform a second observational study with pairs of VI and sighted participants. This second study revealed how the CCIS process can be supported. As an outcome we produced a set of guidelines intended to inform the universal design of CCIS systems.

The term visually impaired is usually employed to denote both individuals who are partially sighted and those who have no vision. Throughout this thesis our focus is on users with no vision who rely on speech-based screen readers to interact with computers and to access the Web. While we did not deliberately exclude the use of Braille displays, the profile of our VI participants was typical of VI users as a whole, in that speech-based output was generally preferred. Speech-based output is significantly less expensive and involves a lower learning curve for users than Braille-based alternatives.

1.2 Motivation

With the rising evidence of CIS practice, research studies have aimed to provide an understanding of the process (Hyldegard, 2009) and solutions (Golovchinsky et al., 2009). The main goal of these studies has been to assist users to collaboratively search for and retrieve information relevant to a shared information need. While representing a growing body of research (Shah, 2013b), these studies have not considered users employing different modes of interaction. Given the substantial amount of research outlining the accessibility challenges encountered by VI users on the web in general, and the relatively small amount of research investigating VI users' web search activities, to our knowledge CCIS activity has never been explored.

Thus there are two important gaps in existing studies that motivate the research in this thesis. The first gap is forming an understanding of what happens during CCIS activity. From Morris's (2008) survey that initiated the research area of CIS, no studies have looked into providing a holistic understanding of what happens in such an activity. In order for us to support the process of CCIS, we aim to firstly understand the activities it involves. This allows us to identify the processes through which collaboration happens, and examine how concepts from "mainstream" Collaborative Information Seeking (CIS) literature, such as division of labour, mutual awareness, results management and sharing appear in a cross-modal context, and look for issues that might occur. Being able to understand the process and its challenges will assist us in finding approaches to best support CCIS, which is the second gap in the current literature. We aim therefore to provide knowledge about the CIS process in a cross-modal context and identify areas for research in supporting the process to develop. In the following section we describe the main research questions (RQs) this thesis aims to answer.

1.3 Research Questions

To address the research gaps outlined above, the goal of the work presented in this thesis is to understand the process of CCIS activity and examine how the knowledge produced from this understanding can be used to support the design of a system to support it. Thus the two main RQs are:

To address research gap one: What happens currently when people perform CCIS?

This question in turn implies a number of RQs introduced and discussed in section 5.3. The objective here is to form a conceptual understanding of CCIS activities when VI and sighted users employ the applications they use every day, such as web browsers, word processors and communication tools, to perform CCIS. These questions look into the of IS and the ways they are performed by examining those stages that are conducted collaboratively; the reasons that motivate these collaborations are also discussed. Relevant concepts identified in the CIS literature (Morris, 2008) - such as division of labour and awareness - are also discussed, and we investigate approaches users employ to divide labour and provide awareness information.

To address research gap two: how might the CCIS process be improved?

The knowledge gained from answering the first RQ informs how we might go about providing approaches to support the CCIS process. The thesis goes on to examine the benefits of these approaches, thus this second major RQ is also broken down into a series of RQs introduced and discussed in section 8.3. These questions aim to specifically examine the ability of the approach taken to support CCIS by looking into the IS process, the strategies to divide labour and exchange awareness information, and the challenges that occur. The major difference between this second study and the study reported in chapter 5 is that study 1 focuses on CCIS when users employ non-CIS specific tools to support the process. The study described in chapter 8 is performed specifically within the context of using a specialised integrated tool to support CIS, with appropriate modifications to enable it to work in a cross-modal context.

1.4 Thesis Outline

In this section, we describe the structure of this thesis and detail the content of each chapter:

Chapter 1 outlines the motivation and overall research questions.

Chapter 2 forms the starting point of this study. Given that the area has not been explored before, this chapter provides a review of related fields that contribute to building a foundation of knowledge for this topic.

Chapter 3 describes the semi-structured qualitative research approach used. It outlines the research methods employed to conduct studies throughout this thesis. In this chapter, we describe the design of the user studies, the instruments used in terms of search tasks and search systems, the recruitment of participants and the data that was gathered and analysed. We also discuss the ethical considerations for the user studies.

Chapter 4 presents a preliminary questionnaire that surveys VI and sighted individuals' personal and search result management habits. It also investigates how often CCIS activities occur between VI and sighted web users.

Chapter 5 describes the observational study (referred to as study 1) that examines the challenges that occur in CCIS activities between pairs of VI and sighted users.

Chapter 6 describes a series of scenario-based interviews that explored how users, both sighted and VI, process the results of web searches. It discusses the possible implications of the findings of both the initial survey (chapter 4) and observational study (chapter 5) and presents possible design suggestions for technical solutions to support CIS in a cross-modal context.

Chapter 7 describes a functionality and accessibility review of mainstream CIS systems. It starts with describing the motivation behind this review. It then presents a survey of the available CIS interfaces, and the process of reviewing the candidate system functionalities. It then describes the accessibility review, including an overview of the approach and details of the results. The chapter also presents the features of the interface chosen for use in the final study (reported in chapters 8, 9 and 10), and the accessibility enhancements we made to this main stream CIS system.

Chapter 8 describes an evaluation (referred to as study 2) that explores the CCIS behaviour between VI and sighted users, using the selected system enhanced with the accessibility improvements described in chapter 7. This chapter starts by presenting the motivations and research questions; it then describes the design of the study. The chapter goes on to discuss in detail the findings from the study that relate to the collaborative aspects of the evaluation.

Chapter 9 presents the findings from the study related to the individual aspects of the process and the individual interactions with the system interface.

Chapter 10 provides a consolidated discussion of the main findings reported in Chapters 8 and 9. This chapter makes direct comparisons where possible with the results from study 1 reported in chapter 5. Findings related to individual interactions and accessibility are also discussed. The chapter also presents the observed effects of using the ACSZ interface on the CCIS process. The chapter concludes by proposing a set of suggestions toward the inclusive design of CIS systems.

Chapter 11 provides an overview of the work carried out as part of this thesis and describes the contributions that each stage made to research. We also outline the limitations of this thesis and discuss the avenues for future work that exist in the different disciplines that the work in this thesis spans.

1.5 Publications

Al-Thani, D., Stockman, T., and Tombros, A. (2015) The Effects of Cross-modal Collaboration on the Stages of Information Seeking. In *Proceedings of 16th International Conference Interacción 2015.* Vilanova i la Geltrú, Spain.

Al-Thani, D., Stockman, T., and Tombros, A. (2013). Cross-modal collaborative information seeking (CCIS): an exploratory study. In *Proceedings of the 27th International BCS Human Computer Interaction Conference,* pages 16-24. British Computer Society.

Sahib, N. G., Al-Thani, D., Tombros, A., and Stockman, T. (2012). Accessible information seeking. In Proceedings of Digital Futures, Aberdeen, Scotland.

1.6 Talks and Posters

An investigation into Cross-modal Collaborative Information Seeking, Cognitive Science Research Group, QMUL, July 2015

Cross-modal collaborative information seeking (CCIS): an exploratory study, Cognitive Science Research Group, QMUL, May 2013

Poster Research Open Day, April 2014.

Chapter 2 Related Literature

2.1 Introduction

The work focuses on investigating and identifying the challenges when people using different modalities perform a collaborative information seeking activity. To the best of our knowledge this area has not been explored yet in research; therefore, this literature review aims to examine fields that will contribute to building a foundation of knowledge for this topic. When people interact using different access modalities to fulfil a certain information need, the interaction process can be challenged by many factors and the overall outcome of collaboration can be negatively affected. In order to study a cross-modal collaborative process it is important to analyse underlying activities and the challenges that arise during this activity. Therefore, this review will look into four different and broad topics:

1. Information Seeking: To study CIS activity, it is essential to study the characteristics of the underlying information seeking process. Section 2.2 reviews models of information seeking and considers the stages of the process. Though the models and theories in this field looked at information seeking as an individual process, an understanding of the process and stages clearly have relevance for the various stages of CIS activity. The area of re-finding previously accessed information is briefly addressed. This is followed by a section that introduces the area of social search and highlights the differences between social search and collaborative search.

2. Collaborative Information Seeking: Sections 2.3 and 2.4 cover the general notion of CIS along with definitions and frameworks introduced to understand it. Sections 2.5 and 2.6 take a closer look at the work done to date in the area of mainstream CIS by presenting the concepts and features of systems that support CIS and exploring the dimensions of CIS. The evaluation of CIS systems is then discussed in section 2.7 by presenting the different approaches through which CIS systems have been explored in empirical studies.

3. Web Accessibility: Since the work involves VI users accessing the web, section 2.8 discusses the work done in the area of web accessibility for VI users in both commercial and in academic research. This section also discusses approaches to web accessibility evaluation. The section concludes by examining the work done in accessible information seeking for VI users to date.

4. Cross-modal collaborative interfaces: Given that the nature of the topic is cross-modal collaboration, section 2.9 covers the rather limited previous research in the field of cross-modal collaborative interaction.

2.2 Information Seeking (IS)

2.2.1 Definition

Information seeking is described as a process that is triggered by an individual's "information need" (Marchionini, 1997). In other words, it is the process a human initiates in order to search for information or enhance their knowledge of a subject. Though it is a fundamental process that we experience in our daily lives, it requires a high level of cognitive effort as emphasized by Marchionni (1997). He stated that the level of cognitive effort required by the information seeking process is similar to that required for learning and problem solving. Moreover, in comparison to web browsing, information seeking requires more cognitive effort and analytical skill (Marchionni, 1997).

2.2.2 Models of IS

Since the mid-1970s and early 1980s, research in this field has focused more on the human aspect of the process. Work by Wilson (1981) and Dervin (1983) is often acknowledged in the literature as the earliest attempts in providing information seeking frameworks. Since then a number of models and frameworks have been developed (Wilson, 1999). Most of the introduced models aim to be general, whilst some focus on specific aspects of the process. Models like Ellis's (1989) information seeking features, Kuhlthau's (1991) process model and Marchionini and White's (2008) information seeking process aim to provide a generalized understanding of information seeking behaviour. Other work like Bates's (1989) Berry-Picking Model and Pirolli and Card's (1995) Information Foraging Theory, argued that the information might not necessarily be static and can change throughout the information seeking process.

These dynamic models emphasized that the process of information seeking involves constant change of information needs as the user interacts with the search system. Bates (1989) introduced the Berry-Picking approach, which relies on two main points. Firstly, throughout the retrieval process and due to the information encountered in this process, the user's information need goes through a series of shifts. Secondly, she argues that a user's information need is never fulfilled by a single retrieved set of results. The user's information need is fulfilled by parts of the information retrieved during the process and is subject to changes in information need.

2.2.3 Stages of IS

A large number of studies have identified and discussed the stages of the IS process (Kuhlthau, 1991; Sutcliffe and Ennis, 1998; Shneiderman et al., 1998; and Marchionini and White, 2008). Despite the variety in the frameworks introduced, the main stages are quite similar. Shneiderman et al. (1998), in their "Four Phases Framework", highlighted that the search process essentially contains four stages. These are outlined below:

- Query Formulation: the stage in which the information need is initiated and the query is formulated.
- Action: the stage in which the search is started.
- Results: the stage in which the search results are presented and examined by the information seeker.
- Refinement: the stage in which the information seeker refines the search term. It is an iterative process which usually reaches an end when the user is satisfied with the information at hand.

Influenced by this framework, Marchionini and White (2008) presented the sub-processes of the IS process. The first three sub-processes are conducted before interacting with the search system. These sub-processes are: recognising the need for information, accepting the challenge to take it forward, and formulating the problem. The authors stressed the impact that the formulation of the problem can have on the effectiveness and efficiency of the search process. In fact, they regarded problem formulation to be the most important stage of the three.

Following the problem formulation stage, the information seeker uses the search system to express the problem, which is the fourth sub-process they presented. In this stage the information seeker enters the query into the search system which generates a number of results for the information seeker to examine. As described by Marchionini and White (2008), the information seekers often spend most of the time at this stage reading and reviewing the results. When the information seeker is not satisfied with the results, the problem can be re-expressed by replacing or modifying the query in an attempt to get better results; Marchionini and White (2008) refer to this stage as problem reformation. Many studies have introduced techniques to support this stage. These techniques include: relevance feedback (Salton and Buckley, 1997), query expansion (Efthimiadis, 1996) and search history (Nielsen, 2007). This stage is iterated until the information seeker is satisfied with the results. The final sub-process of IS is the use of the results, in which the information seeker decides to stop the interaction with the search system and use the results.

2.2.4 Information Re-Finding

Re-finding information is one of the components that attracts much attention in both Personal Information Management (PIM) and IS areas. It mainly refers to the activity of re-finding information previously acquired and in which an effort has been made to store for later use (Jones, 2007). This information may be in the form of electronic documents, emails, appointments (Dumais et al., 2004; Teevan et al., 2004) or information accessed on the web (Capra, 2003; Jones et al., 2001).

Re-visiting or re-finding information on the web has been a salient topic of research in both PIM and IS fields. Studies have looked into strategies that people employ to re-find information. These studies also highlight tools and techniques that people use to support the process of re-finding, such as search engines and browsers, which offer little to support this process (Capra, 2003; Jones et al., 2005; Capra and Perez-Quinones, 2003). Results from the 'Keeping found things found' project, in which they observed the web searching habits of (24) participants in a workplace, showed a variety of methods used. The most frequent method recorded is emailing web links with comments to themselves or other co-workers.

The second most common technique found was actually doing nothing and relying wholly on one's memory to remember keywords to perform the search again. The usage of bookmarks and web history features was rarely observed. A number of research studies have revealed similar findings; a study by Capra et al. (2010) in which they interviewed people about their information re-finding habits revealed that 53% reported an absolute reliance on one's memory to re-find previously found information on the web. Likewise, Aula et al. (2005) surveyed web users and revealed that search engines are used more than bookmark and web history tools for re-finding information. Furthermore a study based on analysing Yahoo! search engine user logs (Teevan, 2007) confirmed that more than 40% of the queries were attempts to re-find previously retrieved results.

2.2.5 Social Search

In addition to using traditional search engines to acquire information, one may ask colleagues at work, email a friend or even post a question on a Facebook wall or on a 'Question and Answer' website (Evans and Chi, 2008; Morris et al., 2010b). This type of search is referred to in the literature as a 'social search'. In the literature, a social search is described as an information seeking activity that benefits from different social aspects including asking a friend, an expert, or people who are willing to help. It can also include searching a database of social content (Morris et al., 2010b).

Until now social search on the web has been considered an under-investigated area of research (Evans and Chi, 2008; Teevan et al., 2011). The enormous increase in the number of social network users ignited the fuse of social search research. According to the Pew Internet Projects, the number of registered Twitter users in 2011 has doubled since 2008 (Smith and Brenner, 2012). Nowadays Web 2.0 content is produced by a wider group of the general public (Cormode and Krishnamurthy, 2008) as a variety of applications are available to edit and publish content on the web. These applications range from blogs and wikis, to social networks such as Twitter and Facebook, and specialised social networks such as LinkedIn.

Studies have emphasized that social search appears to be a very common activity. Evans and Chi (2008) surveyed a sample of 150 web users in which more than 50% affirmed that they do seek social input at a certain stage in the search process. They may seek others' assistance for advice or feedback as well as brainstorming to improve search tactics and chosen query keywords. Another study by Wells and Rainie (2008) also revealed that people rely on a mixture of internet search and social resources to address their information needs.

Studies on social search behaviour have shown that people tend to trust the opinions of people within their social networks. Thus they tend to turn to their social networks to acquire information, especially if they are looking for an answer to a question of a subjective nature (Morris et al., 2010b). Studies have also emphasized that a social search can aid and strengthen the search process (Evans et al., 2010) especially in cases where the process required multiple iterations, brainstorming and interpretation of results. They reported that when an exploratory search activity (Marchionini, 2006) encompasses a combination of web and social searches, the results are better.

The social dimension in the information seeking process was noted in many fields in addition to the IS field. In Library science, Twidale et al. (1997) reported the tendency of information seekers to get help from librarians and other students in the library. In organizational learning literature Borgatti and Cross (2003) introduced a model of information seeking in a social context. They suggested that throughout the information seeking process, people tend to benefit from available expertise in the field and people who are willing to help. In the field of Information Retrieval, Evans and Chi (2008) explored the effects of social context on the IS process. They asserted the importance of social interaction as a main component in the IS process. Their findings (from a large-scale survey in which they raised questions related to the effects of social context on the IS process) proposed a model benefiting from previous efforts in IS and sense-making. In their model they introduced three opportunities in which social interaction can happen during the IS process. These cases are: before, during and after search.

Clearly there are a number of factors that contribute to the rapid development of this field. There is evidence from the studies discussed so far that social context does influence the IS process. Yet very few have tried to build a special tool to support this type of search. However one example, HeyStacks (Smyth et al., 2009) is a browser plugin that allows searchers to benefit from similar searches conducted by users from their own social network.

2.3 Definitions of Collaborative Information Seeking (CIS)

For years web search engines were always built with individual users in mind. This was despite the fact that numerous studies in education and workplaces indicated that there was always a tendency in groups of people to work together in a search task even if they were not asked to do so (Allen, 1977; Twidale et al., 1997; Large et al., 2002). It was not until the last decade when researchers started to look into this area (Morris, 2008). As this field started to emerge, researchers in the fields of Information Retrieval (IR), Human-Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW) knew that reinventing the wheel of traditional information seeking would not be sufficient (Twidale et al., 1997). The social dimension or the human-human interaction component is now added to the process. Various terminologies in the field of IR and HCI have been used to refer to this area of research. These terminologies are: Collaborative IR (Fidel et al., 2000), Collaborative Exploratory Search (Pickens and Golovchinsky, 2007), Collaborative Information Behaviour (Foster, 2006; Reddy and Jansen, 2008) and Collaborative Information Seeking (Morris, 2008; Hertzum, 2008; Shah, 2009).

Though these studies refer to the activity of collaborative information seeking using different terminologies, the definition of this activity remains fundamentally the same. It is defined as the activity performed by a group of people with a shared information need or 'goal' (Morris, 2008). A more detailed definition by Hansen and Jarvelin (2005) described CIS as:

> *"an information access activity related to a specific problem solving activity that, implicitly or explicitly, involves human beings interacting with other human[s] directly and/or through texts (e.g., documents, notes, figures) as information sources in a work task related information search and retrieval process either in a specific workplace setting or in a more open community or environment".*

It is worth mentioning here that there is a principle difference between social search (discussed in Section 2.2.5) and CIS, although both involve the social dimension in their processes. Social search lacks the primary condition of CIS which is a common goal between collaborators (Morris et al., 2010b). Although rarely explored together, Morris (2013) has stressed the importance of considering CIS as a subset of social search, as collaborators with common goals can use social media outlets to communicate and synthesize search results.

2.4 Frameworks and Models of CIS

Despite the rather extensive research in this field in the past few years, there is no consensus over a single model or framework that describes the CIS process. In the past few years, very few attempts have been made in the research to develop models either to describe the CIS environment (Shah, 2009) or to classify the systems supporting it (Golovchinsky et al., 2009). Shah (2009) proposed a layered model of information seeking. The model contains four layers: information, tools, users and results. The information layer refers to the different resources and formats of information contained in the entire search space. The tools layer basically refers to the search engines and the functionality they provide. The users layer includes the users, their profiles and any mechanisms available for personalization. The final layer is the results, ultimately the product of the search process, including all relevant information, users' comments and metadata.

Studies (Hyldegard, 2009; Shah and Gonzalez-Ibanez, 2010) examined the applicability of Kuhthau's (1991) process of individual information seeking in the context of a group. Hyldegard (2009) observed a group of 10 students over 14 weeks when performing information seeking activities and Shah and Gonzalez-Ibanez (2010) conducted a laboratory study involving 42 pairs performing a general exploratory search task. Both concluded that though there are evident similarities in the general stages of the process between individual and collaborative behaviours in information seeking, there are also important differences. The differences are related to the contextual aspects associated with social factors. The results of the studies were similar, both concluding that Kuhlthau's ISP did not completely meet the social dimension of CIS.

Golovchinsky et al. (2009) proposed a taxonomy of CIS collaboration in which they introduced four dimensions of collaboration. These dimensions are: (1) Concurrency: synchronous and asynchronous (2) Location: co-located and distributed. (3) Intent: Explicit and implicit and (4) Degree of which CIS is mediated: user interface level and retrieval algorithm level. These dimensions are further discussed in section 2.6.

2.5 Concepts and Features of CIS

The literature in the field of CSCW has long emphasized that in order to fulfil the design of collaborative interfaces, three aspects should be addressed: control, communication and awareness (Rodden, 1991). While these aspects have been quite predominant in the CSCW Literature, several CIS researchers aimed to define the foundations of CIS systems (Morris, 2008; Farooq et al., 2009; Shah and Marchionini, 2010). Morris (2008) surveyed the collaborative information seeking and information-gathering habits of 240 technology workers. As a result of her study she recommended that in order to have an effective collaborative web search, an interface should support awareness, division of labour and persistence. The remaining part of this section discusses each aspect in detail, in addition to highlighting examples of developed interfaces that support these features.

2.5.1 Awareness

2.5.1.1 Definitions and Models of Awareness

The issue of awareness was highlighted as early as the introduction of CSCW in the mid-80s. In fact, it is one of the most discussed aspects of CSCW in the literature. In the past two decades numerous attempts have been made to define awareness in the context of CSCW and provide models and theories to describe and support it (Dourish and Bellotti, 1992; Gaver, 1992; Gutwin and Greenberg, 2002). Though many attempts have been made to define it, there is neither a clear definition nor a complete model that can be applied in the CIS environment (Shah and Marchionini, 2010). A definition as early as 1992 by Dourish and Bellotti describes awareness as “an understanding of the activities of others, which provides a context for your own activity”. The awareness of both the group members’ individual activities and the activities happening between group members was highlighted as an important aspect to improve group performance.

Similarly a number of research studies in the early CSCW literature attempt to provide theories and models to understand the concept of awareness. In Gaver’s (1992) General Awareness Model he stressed that awareness is an important factor in any collaborative activity; However the level of awareness can significantly differ depending on the type of collaboration. When ‘collaboration is focused’ as he called it, in which users work closely, intensive awareness is required. However less awareness is required when labour is divided between collaborators or the goal between collaborators is not common. Nevertheless he emphasized that even in those cases, a minimal amount of awareness information would potentially improve the performance of the collaborators.

2.5.1.2 Awareness in CIS

Research in the field of CIS has certainly benefitted from the numerous research efforts in the field of CSCW in defining awareness and providing models and frameworks to understand and evaluate it. Coagmento, which is a CIS system introduced by Shah and Marchionini (2010), was designed based on the taxonomy of awareness in CSCW introduced by Liechti and Sumi (2002). In this taxonomy four types of awareness were proposed: (1) Group awareness: the awareness of group members' activities at a given time. (2) Workplace awareness: the awareness of activities in-between collaborators. (3) Contextual awareness: related to the context of the activity and not the collaborators. (4) Peripheral awareness: related to the availability of information that can help the collaborators to perform their activities but not affect their cognitive load.

Based on this taxonomy Shah and Marchionini (2010) emphasized the importance of providing awareness in their CIS interface (Coagmento). They asserted that since each information seeker in the group will be working with different information resources, it is important to keep every member in the group aware of the retrieved information, other members' activities and discussions between members (Shah, 2010a). Coagmento supports synchronous and asynchronous remote collaborative searches. It provides a mechanism to allow users to be aware of other activities. This is done by dedicating views that are updated with other members' query terms, documents, webpages viewed, saved links, and snippets. They also emphasized that providing this level of awareness should not interrupt users' activity and potentially negatively affect collaborators' performance by raising their cognitive load.

The level of awareness made available by an interface can have an impact on the participants' performance and the efforts they make to coordinate. Shah (2013a) studied the messages exchanged between participants in three conditions from Shah and Marchionini (2010).The three conditions were : "baseline awareness" in which the participants can see updates happening in the shared workspace, "personal peripheral awareness" in which participants can see only their own history queries and documents viewed as well as baseline awareness and "group peripheral awareness" which supports the group history of documents viewed and queries submitted in addition to baseline awareness. They found that teams from the first two conditions spend more time and effort coordinating the activity with their partners. This endorses the importance of looking into providing the right amount and type of awareness information to aid the process of collaboration. Participants' engagement and performance were positively affected when providing awareness information about both the stages of information seeking such as queries submitted and documents viewed as well as through the shared workplace such as information stored and comments added by collaborators. In the next two sections we discuss examples from the literature in which awareness of the stages of information seeking and use of a shared workplace were examined.

2.5.1.3 Awareness of the Stages of Information Seeking

According to Shah and Marchionini's (2010) work, group awareness played a crucial role in enhancing both team engagement and performance. They defined group awareness in the context of CIS as the awareness of queries entered and documents browsed and stored by other team members. Awareness of the stages of information seeking, involving the queries formed and results explored and stored have been the centre of attention of many research efforts in the field. The focus for these studies was to provide either awareness in all stages of information seeking or awareness at different stages of the CIS process.

Raising the awareness at the query level has been explored by Fu et al. (2007). They introduced "collaborative queries" in which a user can benefit from others' search experience with the same information need in formulating the query. They stressed the fact that different queries from users with the same information need can be combined to enhance retrieval performance. Other applications focused on allowing the collaborators to view their partner's queries in an attempt to enhance group performance. The WeSearch system (Morris et al., 2010a), a synchronous co-located CIS interface on a tabletop display, provided collaborators with a means to share queries and comments within the group. The queries and comments are colour coded by collaborators. CoSense is a Microsoft developed CIS system that is aimed to support sense-making in collaborative web search tasks. It provides the users with different views of the collaborators' activities in terms of 'query keywords'; documents retrieved and shared comments (Paul and Morris, 2009).

Search results awareness is also explored in which members can view the results of previously conducted searches or view search results of other members within the group. Microsoft's SearchTogether (Morris and Horviz, 2007a), a browser plugin designed to facilitate synchronous and asynchronous remote searching, provides a means of raising results awareness between collaborators. SearchTogether allows the user to explore the findings of other group members. Additionally it provides the users with metadata of webpages such as the names of users who visited them, users' ratings of webpages, and comments by other group members. It is worth mentioning here that the comments feature is available in most developed CIS systems, as initial evaluation results of these systems showed a high level of usage of this feature (Morris and Horvitz, 2007a; Paul and Morris, 2009; Shah and Marchionini, 2010).

Recent work by Capra et al. (2012) highlighted the significance of providing awareness at the level of search results. Using their Results Space interface, awareness was aided by showing team members visited and rated search results. The results of their laboratory-based study with pairs of participants showed that this approach not only helped participants in avoiding any duplication of effort, but also enhanced their collaborative sense-making. Participants were observed checking the search results which had been previously rated by their team members to form an understanding of the search results found and to move forward toward their search goal. A comparative study (Chen et al., 2014) by the same group looked into participants' CIS behaviour patterns with and without an awareness mechanism in place using their Result Space interface. The investigation showed that the participants were significantly more engaged in the collaborative process and the information found was more consistent.

2.5.1.4 Workspace Awareness

Another type of awareness highlighted in the work done in this area is workspace awareness. While awareness of the stages of information seeking is specifically tied to CIS, workspace awareness has long been discussed and examined in the wider discipline of CSCW. It is described as the understanding of the group members' past and current activities in the shared workspace (Gutwin and Greenberg, 2002). In the context of CIS, work by Paul and Morris (2009) on the CoSense systems interface, two special views were employed to facilitate workplace awareness. These views were called the 'timeline view', used to show all members' activity ordered chronologically, and the 'workspace view', which group members used to organize and view retrieved information, add comments and save webpages and documents of interest. An observational study with a group of three participants using the interface revealed that though it is important to be aware of queries and results explored, it is equally important to be aware of other group members' activities in the shared workspace. Looking into the number of times and time spent accessing the 'workspace view', they observed that the highest number of accesses recorded was in the asynchronous collaboration condition. This illustrates the fact that workspace awareness is important to aid the process of sense-making.

Like CoSense, Coagmento (Shah and Marchionini, 2010) provides a view to support group activity. The view has also been called the 'workspace view;' which allows users to store links and snippets but not comments. To facilitate workspace awareness Coagmento provides information about updates that are shown in the workspace view in a dedicated area on the sidebar of a browser. In their study (Shah and Marchionini, 2010), which examines participants' satisfaction and ease of use, they showed that providing awareness mechanisms in this workspace view had a positive effect in engaging collaborators. They also observed that when there is no awareness mechanism in place, the number of times the users accessed the workspace view in an attempt to facilitate awareness was higher.

The mechanisms previously discussed were mainly focused on remote collaboration. For co-located collaboration, workspace awareness can be facilitated differently. Systems that were introduced to support CIS have mainly used shared displays either with multi-touch screens or with a separate input device for each group member. These interfaces are rich in terms of awareness as collaborators are able to monitor their team member's gestures and actions. In such interfaces sound can be added to provide or enhance awareness. Físchlár-DiamondTouch provided auditory icons that were related to each type of action performed in the shared workplace (Smeaton et al., 2006). Evaluating the interface with users showed good levels of satisfaction and improved recall and precision rates compared to when no awareness mechanism was provided (Smeaton et al., 2007). While Smeaton et al (2006) used sound to facilitate workspace awareness in their tabletop systems, Morris et al. (2010a) provided each user of the tabletop display with a separate window with a history of query terms used which moved slowly above the individual dedicated windows. In post-study interviews, participants expressed their satisfaction with the mechanism for viewing team members' current queries by simply glancing at these windows.

2.5.2 Division of Labour

In comparison to the issue of awareness, which has been examined in depth in both CSCW and CIS, the division of labour has been under examined. Division of labour can be described as "the process of dividing up the group task across collaborators in order to share the workload across the group" (Foley and Smeaton, 2010). From exploring the CSCW literature, several strategies for labour division can be found (Ellis et al., 1991; Sharples, 1993; Poltrock and Handel, 2009). Taking into consideration the nature of IS stages and the fact that there are no clear boundaries between these stages, Division of Labour strategies in CSCW cannot be applied (Foley and Smeaton, 2010). Nevertheless, a number of strategies have been established in the CIS literature. These strategies are recognized and implemented according to the search task (Taylor, 1968), the availability of resources (Morris et al., 2008) and the role and expertise of the collaborators (Pickens et al., 2008).

Morris's (2008) survey revealed two types of strategies: 'divide and conquer' and 'brute force'. Which of these strategies was employed depended on the nature of the search task. Moreover, the location of the collaborators may also influence these strategies. The first strategy (divide and conquer) involves users working together explicitly throughout the search activity. This is in addition to dividing the task into sub-tasks that can be performed separately by group members. Though the sub-task can be performed separately, collaboration is always present throughout the CIS activity. The ‘brute force’ strategy, on the other hand, involves users not collaborating at all and involves all group members performing the entire task separately. This type of strategy can involve a waste of effort and low performance, as the same information can be explored and found by all group members, which can result in a lot of redundancy. In an effort to eliminate redundancy when a group of users employ the brute force strategy, Foley and Smeaton (2010) introduced an algorithmically mediated system that supported division of labour in the ‘brute force’ strategy. Their algorithm works by removing websites visited by other group members who entered the same query keywords from the users’ search results. From a user interface perspective Morris and Horvitz (2007a), in the SearchTogether system, allowed collaborators to divide the search results in two ways. The first approach was called “Split Search” which is the default. This approach divides the results among collaborators on the user-interface level. The second approach, called “Multi-Engine Search”, sends the queries to different search engines and then presents search results for each search engine to one of the collaborators.

Another way that the division of labour may be accomplished when available technology resources are limited occurs in classroom or library settings where a group of users share the same computer. This type of division of labour is referred to as ‘the driver and the observer’ model. It can be considered as a type of guided search where the user ‘driver’ controls the input device and the ‘observer’ makes suggestions (Amershi and Morris, 2008). To address this type of situation, Amershi and Morris (2008) introduced the CoSearch software that allows a group of users to collaborate using one computer and multiple input devices. It also allowed users to collaborate using their mobile phones. Each member of the group is identified by having a distinct font and cursor colour.

In some cases division of labour is done according to group member expertise. From performing observational studies on two healthcare teams, Reddy and Jansen (2008) argue that CIS activities are triggered by lack of domain expertise, the complexity of the information need and the availability and accessibility of resources. In the model of Collaborative information behaviour they introduced they assert that because of these different triggers, labour can be divided according to available resources and expertise. In systems that support this type of division of labour, search results are spilt based on collaborator expertise. Morris et al. (2008) introduced the smart split search system. This system looks at terms entered by users and their web history and creates user roles accordingly. The search results are then divided according to the created roles. Cerchiamo is another example which was introduced by Pickens et al. (2008). Cerchiamo divides the labour between two collaborators. One collaborator is the ‘preceptor or the gatherer’, which investigates new fields of information, and the other collaborator is the ‘minor or the surveyor’ which looks at and explores each new field in detail. Delegating the task of dividing labour to the CIS system itself might have some benefits in lowering the cost of communication and coordination between group members. However Kelly and Payne (2013) argue against its reliability and highlight its negative effects on the individual and group sense-making process.

The final type of division of labour found in the literature is the more traditional guided search. This type of guided search typically occurs in libraries where a specialist librarian (usually called a reference librarian) guides and helps students to search for required information. In this case the librarian usually works as a mediator between the information seeker and the information (Taylor, 1968). Nowadays technology supported solutions have been added to library websites and portals. These solutions allow information seekers to chat with librarians and go through a guided search in a library catalogue via the web (Morris and Teevan, 2010).

2.5.3 Persistence

In asynchronous collaboration there is a need to store shared search sessions, so that they are available for other members of the group once they resume the search. To achieve optimum productivity not only should shared search sessions be available but similarly group decisions, comments, stored links, and page rankings (Morris and Horvitz, 2007a). The importance of the persistence issue was highlighted in early research in the field of CIS. In their library-based study Twidale et al. (1997) recommended a ‘saved search’ feature in a library database. The feature allowed collaborators to save their searches and return to them for later use. In addition, if students had difficulties in searching a particular reference, they could save the search and return to it once a reference librarian was available.

Morris (2008) and Capra et al. (2010) found that the lack of a tool that supports asynchronous collaboration means that collaborators mostly tend to use emails and shared documents; email exchanges were used more frequently than other means. Therefore, the issue of persistence was always in the mind of asynchronous CIS system designers. The 'storable, sharable search' (S3) system is a browser designed by Morris and Horvitz (2007b). The main objective of this browser is to aid asynchronous CIS between collaborators. Retrieved links can be shared with offline collaborators. The S3 browser automatically stores keywords and web sites visited and saves them into an XML file which can be saved and emailed to other collaborators. A collaborator could then load this file for later use. Other asynchronous collaborative systems (e.g. SearchTogether, Coagmento and CoSense) also support this persistence mechanism.

2.6 Dimensions of CIS

Traditional mainstream CSCW has long recognized two main dimensions of collaboration: location and time (Rodden, 1991; Shneiderman and Plaisant, 2004). Both dimensions were also identified in a study of collaborative activities in a library environment by Twidale et al. (1997). However more recently Hansen and Jarvelin (2005) proposed a classification of CIS activities benefiting from the vast literature in the field of CSCW. In their research they added two new dimensions, these being the level of mediation, and loosely or tightly coupled collaborative activities. Related to their model Golovchinsky et al. (2009) proposed a taxonomy of CIS collaboration. This taxonomy expanded the Hansen and Jarvelin (2005) model, introducing four dimensions of collaboration, which this section will explore in greater detail. These dimensions are:

– Concurrency: synchronous and asynchronous.

– Location: co-located and distributed.

– Intent: Explicit and Implicit.

– Depth of Mediation

Moreover a publication by Morris and Teevan (2010) stressed that the role of the collaborators and the task performed should also be considered essential dimensions of CIS systems.

2.6.1 Time and Space

Time and space were recognized at an early stage in CSCW literature as the dimensions of systems that support CSCW (Rodden, 1991). In terms of time, collaboration can either be synchronous or asynchronous. In synchronous collaboration group members work together over the same or similar time frame, while in asynchronous collaboration group members collaborate by typically making their contributions at different times from one another. In terms of space collaboration falls into two categories; either co-located, where group members work together in the same place, or distributed, where collaborators work in distinct geographical locations.

When collaboration happens synchronously collaborators can either be co-located when performing the search task or work remotely and use appropriate means to facilitate communication. The communication mechanisms employed range from traditional tools to specially designed means for CIS tasks. Traditional tools can include instant messaging, texting, phone calls, emails, or updating shared documents stored somewhere on the web or on a local network. The field of CSCW has long recognized the potential of this type of collaboration and numerous tools have been researched and developed and can be found in the market now (Dingwall et al., 2014). These tools mainly rely on audio and/or video conferencing such as Skype [1] and Cisco WebEx[2] meeting.

Early studies in CIS have revealed a major tendency for CIS to occur synchronously (Twidale et al., 1997; Amershi and Morris, 2009). Twidale et al. (1997) introduced ARIADNE to facilitate collaboration in a library environment. At the present time, systems like QuestionPoint[3] have been built to support remote synchronous guided searches in library catalogues. Furthermore Desktop applications and browser plug-ins have been designed to support this type of general

[1] http://www.skype.com/en/
[2] http://www.webex.co.uk/
[3] http://www.questionpoint.org/

purpose CIS such as SearchTogether (Morris, 2007a), CoSense (Paul and Morris, 2009) and Coagmento (Shah and Marchionini, 2010). They provide views in which collaborators can store links, add comments and store documents of interest to share with other group members, as well as providing an instant messaging feature. On the other hand intensive efforts have been undertaken to design systems that support co-located synchronous CIS. These systems are often rich in their support of awareness, as an attempt to utilize none-verbal communication during the process and hence to enhance the performance in the workplace. Prototypes have been developed such as TeamSearch (Morris et al., 2006), Físchlár-DiamondTouch (Smeaton et al., 2006) and WeSearch (Morris et al., 2010a). These prototypes are all table top display systems. Another example system that supports co-located CIS is Co-Search (Amershi and Morris, 2008) in which multiple group members can share the same computer and use multiple input devices to collaborate.

In tasks that involve complex decision-making and require a considerable amount of information to be retrieved, it is likely that searches may be done over multiple sessions (for instance group members working on writing a research paper). Therefore such an activity may involve group members performing searches over different periods of time. In this situation, there is a need to preserve previous search sessions and activities performed by group members (Golovchinsky and Diriye, 2011). Studies that investigated group member communications in multi-session searches revealed that the most common mechanisms used are sending links and documents of interest via email and creating mail groups (Morris, 2008; Capra et al., 2010). Though such an approach is found reliable by users, studies that support asynchronous remote CIS have examined enhancing the users' experience and performance when conducting multi-session searches (Morris and Horvitz, 2007b; Golovchinsky and Diriye, 2011). These studies emphasized that in this type of collaboration, a mechanism to support persistence is mandatory. The previous search sessions can either be uploaded (Morris and Horvitz, 2007b) or can be found upon accessing the system (Morris and Horvitz, 2007a; Paul and Morris, 2009; Shah and Marchionini, 2010).

2.6.2 Intent: Explicit and Implicit

Golovchinsky et al. (2009) introduced intent as a dimension of collaboration, emphasizing that shared information need can either be explicit or implicit. When considering a shared implicit information need, the first application that comes to mind is a recommender system. In recommender systems we receive recommendations based on similar behaviours or opinions to ours (Teevan et al., 2009). Taking Amazon.com (Linden et al., 2003) as an example, when we purchase a movie or a book we get a list of recommendations based on users with similar behaviour. In the literature this type of asynchronous and anonymous collaboration is also referred to as 'collaborative filtering' (Belkin and Croft, 1992). Shah (2010b) and Foley and Smeaton (2010) argued that though in this type of interaction, the information need is common, collaborators don't actually work together or even know the people with whom they share behaviour. Therefore collaborative filtering cannot be considered as a CIS activity.

In contrast explicit collaboration happens when a group of information seekers who share a common information need work together toward a common goal. Collaborators in explicit CIS work together in retrieving, sense-making and managing retrieved information (Golovchinsky et al., 2009). Numerous examples can be referred to in the CIS literature that support explicit collaboration (e.g. Morris and Horviz, 2008; Paul and Morris, 2009; Shah and Marchionini, 2010).

2.6.3 Level of Mediation

Pickens et al. (2008) stated that although collaboration is supported at the user interface (UI) level such as SearchTogether (Morris, 2008) and WeSearch (Morris et al., 2010), the search engine itself does not support collaboration, which in turn has an impact on the efficiency of search. Collaborators may retrieve similar results and spend a considerable amount of time and effort trying to remove duplicates and integrate results. To address this issue they proposed that collaboration should be supported in the UI, as well as at the retrieval algorithm level. They developed an algorithmically mediated collaborative search engine which was then evaluated using an inter-subject design. In the evaluation one pair of participants used the system while another pair used the standard search engine. The results showed that the number of unique documents found was noticeably greater when the tool is used. Moreover since the tool avoids replicated search results, the overall efficiency of the search was improved.

2.6.4 Searchers Roles

Studies revealed that collaboration happens in a variety of situations and environments ranging from libraries and schools to information workers, engineers and even in families (Twidale et al., 1996; Allen, 1977; Large et al., 2002; Morris, 2007). However collaborative activities in all these situations are not the same and can be highly dependent on the context of the task. CIS literature classifies collaborative activities to involve either symmetric or asymmetric collaboration (Morris and Teevan, 2010).

In symmetric collaboration collaborators have similar roles and information is available to all group members equally. A number of previously discussed examples are designed to support such a collaboration, including SearchTogether (Morris and Horvitz, 2007a), CoSense (Paul and Morris, 2009) and Coagmento (Shah and Marchionini, 2010).

Asymmetric collaboration on the other hand happens when collaborators fulfil different roles (Morris and Teevan, 2010). Hence information is supplied to each team member according to their role(s). O'Day and Jeffries (1993) introduced three levels of collaborative activities that can be considered asymmetric in terms of information sharing and search results management. They suggest that a collaborator (1) broadcasts interesting information to the group (2) acts as a consultant (3) stores information electronically on behalf of the group. Although asymmetric collaboration has long been identified in organizational and librarian literature, very few have looked at it in the context of CIS. Cerchiamo by Pickens et al. (2007) and Smart Split by (Morris et al., 2008) are examples in which information is available to users according to expertise and roles.

Furthermore Shah (2010b) has attempted to provide a categorisation of CIS according to collaborator roles. In a survey, he interviewed (11) students and academics in the field of IR. He described three major types of collaboration that happens according to an individual role. They are: forced collaboration, peer-to-peer collaboration and expert-novice asymmetric collaboration. The first two types are categorised as symmetric collaboration. In the first type collaborators are forced to perform CIS together; this type occurs in a classroom setting when the tutor forms a group and asks them to research a certain topic together. The second and most common recorded type of collaboration is when collaborators choose to perform collaboratively an information seeking task together such as jointly writing a research paper or planning a trip together. The last type is asymmetric collaboration, an example of which being when a student seeks help from an academic in a specific research topic.

2.6.5 Tasks and Context of Search

CIS was first explored in a highly layered information environment (Twidale et al., 1997) however as technologies started to take over many manual tasks, researchers in many fields started to look into tasks that modern day technologies can replace. A number of specialised collaborative search tools were designed to serve specific tasks. C-TORI (Hoppe and Zhao, 1994) developed an application that allows group members to collaborate while searching a relational database. Krishnappa et al. (2005) designed a tool that allows pairs of medical specialists to collaboratively look up medical information in a medical database. Additionally, Halvey et al. (2010) introduced a collaborative search interface for multimedia.

As research in the area of CIS progressed, it was clear that researchers started to look at general collaborative search tools (Morris and Teevan, 2010; Shah and Marchionini, 2010). A large-scale survey conducted by Morris (2013) to investigate web search habits revealed that generally people tend to collaborate more in personally oriented tasks than business oriented tasks. A wide variety of tasks were mentioned, from simple online shopping to organizing social events.

2.7 CIS Evaluation

Given the complexity of the context and the multi-dimensional nature of the issues involved, the CIS evaluation process can be considered challenging. The evaluation framework needs to consider the user, the system and the collaboration. CSCW literature has long considered evaluation one of the major challenges due to the complexity of the process (Neale et al. 2004). Andriessen (1996) defined the four research dimensions under which CSCW evaluation takes place as: individual interaction with the interface, communication structure and behaviour, group interaction with the interface, and the medium of communication. On similar lines, Shah (2014) suggests that there are three dimensions present in empirical studies of CIS: the user, the interface and the collaboration. Shah (2014) referred to these dimensions as system-focused, user-focused and collaboration-focused dimensions. He argued that looking at one dimension might not be enough to fully understand the process of CIS and the context in which it is being examined. He asserted that a balanced approach would involve looking at the process from more than one perspective (Shah, 2014). This section provides an overview of the evaluation approaches to CIS.

2.7.1 System-focused Evaluation

Studies which are system-focused have their roots in the Information Retrieval (IR) domain. These studies evaluate the effectiveness of a CIS engine (Pickens et al, 2008) as typically in such studies the interest is in how effectively the collaboration is supported at the search algorithm level. IR measures – such as precision and recall, the number of relevant documents found etc. – are often used in evaluating a CIS interface (Shah and Gonzalez-Ibanez, 2011; Pickens et al, 2008; Smyth et al., 2005). System based evaluation rarely looks into participants' interaction with the interface; in fact they usually rely on simulation-base experiments.

One of the early system-focused evaluations was by Smyth et al. (2005) who developed a search engine which benefited from search results that had been judged to be relevant for past queries in responding to similar queries. They reported an improvement in the quality of the retrieved results which in turn led to an enhanced collaborative search experience. Another notable work in this area is the work by Golovchinsky and his group; Pickens el al. (2008) developed an algorithm to support role-based search and demonstrated its effectiveness in enhancing search team productivity and communication levels. The increased relevance of retrieved results was used as a measure for team productivity.

2.7.2 User-focused Evaluation

Looking into the literature, it is clear that the majority of the empirical studies in this field are user-focused. In these studies, the 'goodness' of the interface is measured using instruments taken from HCI and cognitive science literature. These instruments can be a combination of both quantitative methods such as survey results, log data and usability measures, or qualitative methods such as interviews, diaries and focus groups. To collect initial requirements for designing a CIS interface, Morris (2008) has conducted a survey while Shah and Marchionini (2010) has conducted a series of interviews.

Following the development of an interface, the majority of the studies applied a traditional usability measures approach. Morris and Horvitz (2007a) and Shah and Marchionini (2010) used a questionnaire in an attempt to evaluate a CIS environment from a user perspective. Kelly and Payne (2014) performed semi-structured interviews with participants who were asked to use a CIS system in their own time for an extended period that ranged from (14) to (35) days. The aim of their study was to understand the usability of the tool when performing multi-session self-selected CIS tasks. Using a combination of approaches is also popular. Amershi and Morris (2008) used a combination of survey, user logs, and observer notes to evaluate the CoSearch system, described in 2.5.2.

Measures derived from psychology have also been used to explore the effects of CIS on users. Shah and Gonzalez-Ibanez (2011) used NASA-TLX (Hart and Staveland, 1988) to measure users' perceived cognitive load during the CIS task. Using this measure, they were able to identify that users tend to put more effort into co-located collaboration than into distributed collaboration. Measuring emotions and the effectiveness of the CIS process was also explored by Wilson and Schraefel (2009) and Gonzalez-Ibanez and Shah (2014); both studies employed the Positive and Negative Affect Scale (Watson et al, 1988) to explore group dynamics in the CIS context.

2.7.3 Collaboration-focused Evaluation

In the previous section although the evaluations involved users, these studies took place in laboratory settings and would rarely observe the user-user interaction. Shah (2014) highlights the need for more observational and ethnographic studies that focus on the interaction between collaborators. He asserts that although this is the core of the CIS process and that this is what differentiates it from individual IS, it is rarely studied on its own. Collaboration-focused studies investigate the different aspects of collaboration such as division of labour, awareness and cognitive load with qualitative data analysis as a main method.

One such work is by Foster (2010), who developed a coding guide for analysing peers' conversation during an educational information seeking activity. In this activity, students were asked to form groups of three or four and work collaboratively to search for information about a specific topic. The coding guide he developed was informed by the 'sequential organization of spoken discourse' analytical framework which is a language-based theory of learning developed by Wells (1999). The study suggests generic structuring of the conversations between collaborators to understand the properties of effective collaboration. Foster (2009) suggests that understanding collaborative information seeking is far more detailed than merely looking into the retrieval of information and interaction with the interface. He encouraged testing the developed coding guide against empirical materials and clearly highlighted the lack of an existing framework for analysing CIS activities. Tao and Tombros (2013), who also pointed out the need for a framework for analysing CIS behaviour, have investigated the sense-making behaviour in CIS of 24 participants working in groups of three to perform a web search activity. The study used qualitative analyses of screen-recording as well as groups chat logs. The outcome highlighted the challenges the ad hoc tool imposes on collaborative sense-making and suggests design implications to aid the process.

In a recent study (Al-Thani et al., 2013) as a part of this PhD work, reported in Chapter 5, we examined the interaction that happens between sighted and VI users when collaboratively searching the web by analysing users' conversations in co-located and distributed settings. Using qualitative analysis, we studied the transcriptions of users' verbal conversations and chat logs, as well as observing users' interaction with the applications. This approach helped in determining the differences between the settings in terms of the type of information exchanged, the way work was divided and the challenges encountered. Extensively exploring the conversation dialogues between participants can provide a holistic understanding of how collaboration happens. Shah (2013a) reviewed collaborators' chat messages from a laboratory study he previously recorded (Shah and Marchionini, 2010), briefly described in section 2.5.1. By using this analytical approach, he was able to identify behaviour patterns that occur when different awareness mechanisms are employed.

2.8 Web Accessibility

This section starts with an overview of the web accessibility guidelines and regulations. It then looks into research efforts made toward tackling the barriers VI users face when accessing the web.

2.8.1 Web Accessibility Guidelines and Regulations

Web accessibility is a broad term that refers to the ability of making information on the web accessible for people with disabilities (Paciello, 2000; Thatcher et al., 2003). Studies have shown that there are a number of barriers to achieving web accessibility. These barriers include the content of webpages, web agents such as web browsers and media players, the compatibility of assistive technology tools with web technologies and, most importantly, the rapid growth of Web 2.0 technologies. This rapid rate of web technology growth has outpaced assistive technology, rendering it insufficient for many users.

As the internet integrates more into our daily lives, web accessibility becomes more than merely a moral obligation that is optional to satisfy. In fact, it is becoming a legal obligation in many developed countries. Governments in the United Kingdom, United States, and Australia have already integrated accessibility to Information and Communication Technologies (ICT) into their legislation systems by either specifically implementing their own guidelines or by adapting the World Wide Web Consortium (W3C) guidelines. There are a range of guidelines that are produced by governments, committees and commercial companies. These include the following: Web Accessibility guidelines were produced by the Web Accessibility Initiatives (WAI) group which was established by the W3C (Chisholm and Henry, 2005), Section 508 Guidelines[4] released by the US in 1998 as an amendment by the Rehabilitation act of 1973, AFB[5] (American Federation of the Blind) Guidelines produced by IBM's Human Ability and Accessibility Centre[6], and Sun Microsystems Accessibility Design Guidelines were introduced by Bergman and Johnson (2001). The W3C- WAI set of guidelines is the most broadly accepted.

WAI produces an extensive range of guidelines to cover most aspects of Web accessibility. The most notable set of guidelines is the Web Content Accessibility Guidelines (WCAG) which addresses the accessibility of information on webpages including text, images, forms, sounds, and all web interactions. The WAI group emphasized that in order to reach a standardized accessible web, there are three dependent main components that have to work together. These components are the web site, the web authoring tool and the web browser. The WAI group recommended that these three components must adhere to the guidelines in order to ensure accessibility (Chisholm and Henry, 2005). Therefore, the WCAG was published with two other sets of guidelines: Authoring Tools Accessibility Guidelines (ATAG) and User Agent Accessibility guidelines (UAAG) (Treviranus, 2008).

WCAG 1.0 was the first set of recommended guidelines produced by the W3C WAI group in 1999. Within a couple of years of producing their first set of guidelines, in year 2000 the WAI

---

[4] https://www.section508.gov/
[5] http://www.afb.org/Section.asp?SectionID=57&TopicID=167
[6] http://www-03.ibm.com/able/guidelines/

group announced their plans to provide a newer version. The WAI group aimed to address the shortcomings and limitations in its first version. A draft version of WCAG 2.0 was published in 2003 and the full version in 2008. Basically, it is a non-technical-specific document targeted to help web designers and content authors in creating accessible websites.

In WCAG 2.0 four primary principles are defined (POUR): Perceivable, Operable, Understandable and Robust. Each principle has a number of normative guidelines. These guidelines resemble the goal which the web or content developer has to satisfy in order to have an accessible website. Each guideline is accompanied by a number of ‘success criteria’. The aim is to insure the testability of the guidelines. Each success criteria is marked by either A, AA, or AAA. This resembles the level of conformance to the WCAG 2.0 when evaluating a website. Level A is considered as the minimum level of conformance (Caldwell et al, 2008). The four principles are discussed in brief below (Ellis and Kent, 2010):

- Perceivable: The information presented needs to be perceivable to a diverse set of users. This means that the user must be aware of the information presented.

- Operable: This principle encourages providing different interaction modes to ensure that a website is fully operable for a diverse set of users. The interface must not contain an interaction that a user is not able to perform.

- Understandable: The content and the interaction must be equally understandable to all groups of users.

- Robust: Content rendered by different assistive technology tools must be reliable and robust enough to convey the information in a timely manner.

ATAG 1.0 became a W3C recommendation in 2000 and its most recent version is ATAG 2.0. These guidelines are primarily targeted at authoring tool developers. They provide guidance on building authoring tools that help authors to produce accessible content. With the development of Web 2.0 the phrase ‘authoring tools’ encompasses a wide variety of applications, from simple web editing applications and content management systems, to blogging and social media websites (Treviranus, 2008). The guidelines consist of two main parts: the first part is about making authoring tools accessible, and the second part is to enable authors to produce content that conforms to WCAG. Treviranus (2008) stress that with the web increasingly becoming an essential medium for social activity, equal participation becomes an important goal to which all authoring tool providers need to adhere. Section 2.8.2 will discuss the accessibility challenges currently faced by users in Web 2.0.

Another essential component of the Web experience is the user agent which renders the web content to the user. These applications are the gateway to the web for users. They include Web browsers, media players and at times assistive technologies. The W3C produced UAAG to guide the development of user agents that are accessible to people with disabilities (Henry and May, 2009). As indicated in UAAG, addressing accessibility in user agents can certainly enhance the accessibility of the web content rendered through these agents. UAAG 1.0 is the recommendation. However UAAG 2.0 was released as a Draft in 2013. In UAAG 2.0, the aim is to lay the path for future generations of Web browsers by suggesting alternative information about technologies and platforms the user may use. Furthermore the guidelines in UAAG 2.0 also update the UAAG 1.0 guidelines, to align them with WCAG 2.0 and ATAG 2.0.

2.8.2 Accessibility Challenges in Web 2.0

There are numerous attempts to define Web 2.0. Yet, there is no standardized definition. In short, Web 2.0 is the internet today, which is characterized by dynamic web content, users' collaboration via social networks, multimedia sharing and all the interactivity this involves. Web 2.0 can be looked at from two different perspectives. Firstly, it can be looked at from the user perspective. O'Reilly (2007) introduces criteria to differentiate between a webpage that conforms to web 1.0 and a webpage that conforms to Web 2.0. Secondly, it can be looked at from a technology perspective, in which rich internet applications (RIAs) are used to create web applications today. RIAs refer to a family of web solutions characterized by a common goal of extending the user interaction beyond the conventional hypertext-based web. RIAs are usually single page applications that contain individual page elements that can be refresh separately and dynamically. Developers can define numerous interaction events in these elements. These elements are built using technologies such as JavaScript and Asynchronous JavaScript and XML (AJAX) (Fraternali et al., 2010). There are numerous factors that have driven RIAs' rapid growth, ranging from new technologies to market forces. However these rapid advances have made it even more difficult for accessibility efforts to keep up.

It has long been reported that assistive technologies have struggled to keep pace with rapid development of content-based technologies in the web (Gibson, 2007; Kern, 2008, Brown et al., 2012). The main issue resides with handling Java Script and Ajax, which are the core technologies that deal with dynamic content (Steen-Hansen and Fagernes, 2015; Almeida and Baranauskas, 2012). When accessing webpages that contain areas or widgets that are dynamically updated, these changes are not rendered using screen readers (Brown et al., 2012). Unlike WCAG 1.0, which has explicit guidelines to advise developers to avoid these technologies, WCAG 2.0 has focused on providing accessibility-supported ways of using these technologies to develop accessible web sites and applications[7]. While these web technologies can be accessible when developed properly, accessing PDF files on the web using screen readers is an on-going issue[8].

There are two main reasons behind the persistence of this issue. Firstly, PDF documents are not always designed by their authors to be compatible with screen readers. Secondly, PDF documents can be produce by numerous software packages, and the majority of this software does not ensure the production of accessible PDF documents. These issues mirror internet accessibility issues that occur when a web designer fails to follow the accessibility guidelines of the W3C-WAI.

On the technical prospect W3C accompanied its WAI set of guidelines with a specification suit which provides a mechanism whereby web content and web applications, in particular those developed using JavaScript, AJAX and related technologies, can be accessible to people with disabilities. It aims to address the technical obstacles by adding semantics to the code of a

[7] http://www.w3.org/TR/UNDERSTANDING-WCAG20/conformance.html

[8] http://www.adobe.com/accessibility/pdf/pdf-accessibility-overview.html

website as a means of supporting communications between the user, the website, the user agent and the assistive technology (Craig et al., 2010). This provides a better representation of the website through the user interface, and improves user interaction, including with the dynamic components of a website (Gibson, 2007). WAI-ARIA (Craig et al., 2010) was released as a draft in 2008 and in January 2011 was announced as a W3C recommendation. WAI-ARIA 1.1 was published as a First Public Working Draft on 26 September 2013 with only one change from WAI-ARIA 1.0 as announced by W3C.

WAI-ARIA 1.0 can be described as a technical specification that supports the applicability of the WACG 2.0 in the presence of RIA technologies. It is clearly stated that this version targets two groups of users: users of screen readers and users who are not using a mouse or other pointing device. Hence they focus on enhancing navigation, easing the way page components are reached and providing concurrent access to dynamic data. They permit keyboard access to all website components. This is done by adding semantics to the HTML code, as more semantically enhanced code will help assistive technology (e.g. screen readers) render Web 2.0 components more accessibly (Fogli et al., 2010). Though HTML5[9] introduced the use of more semantic tags into the HTML dictionary, the need for considering the implementation of WAI-ARIA elements remains essential for achieving web accessibility in RIAs (Faulkner, 2010).

Studies have noted that WAI-ARIA mark-up standards are rarely used (Kern, 2008; Brown et al., 2012), yet very modest attempts have aimed to solve this issue in the research. Chen et al. (2013) presented a technique to help screen readers identify the ‘widgets’ that are dynamically updated by automatically analysing the code. They presented an algorithmic technique that examines webpage code for dynamic widgets that are not identified by WAI-ARIA tags. A prototype of this application has been examined on fifty websites and was able to identify 61.98% of the dynamic widgets (Chen, 2013).

As with academic research, there is very little work that has been done in the commercial sector to address this gap (Hailpern et al., 2009). Brown et al (2012) reported the capability of screen

[9] https://www.google.co.uk/?gws_rd=ssl#q=HTML5

readers used by VI participants who described their experience of browsing a set of ten webpages: none of these pages catered for the use of WAI-ARIA. The study stated that though the new updates in the content can be accessible to users using newer versions of screen readers (such as Job Access with Speech[10] (JAWS) version 10 and 11, Ocra[11] with Firefox version 3, Supernova[12] and Window-eyes[13]with Internet Explorer (IE) version 7), the user is never explicitly notified about dynamic changes. Additionally, some dynamic content is not accessible through the default means of navigation, and the user is required to change the navigation mode to gain access to added dynamic content. Brown et al (2012) stressed that the dynamic content is not an issue that is specifically tied to screen readers or browsers but a design consideration that needs to be tackled by web designers and developers. They stated that WAI-ARIA has the potential to address this fundamental design issue. The way dynamic content is defined by the web developer or authoring tools using available mark-up should be semantically sufficient for assistive technology tools to render (Moreno et al., 2008).

Another issue relating to web accessibility is the lack of awareness and knowledge of Web accessibility issues on the part of web Developers. This has an impact on both the users and the screen reader providers. In a recent study, 85% of web developers indicated the need for more accessibility training and the need for knowledge in fields such as inclusive design and about users of assistive technologies (Lopes et al., 2010). The need for expertise concerning web accessibility in general and about WAI guidelines and technologies specifically has been highlighted in WAI-group documentation (Caldwell et al., 2008; Craig et al., 2009). The challenge in this case is that web developers need to have knowledge in a variety of fields ranging from core technologies to accessibility. Yesilada et al (2009b) conducted a study which investigated the importance of expertise availability in evaluating websites' accessibility. The outcome of their study stressed that the availability of expertise has a major impact on the process of website evaluation and returns more reliable results. Moreover, Cooper (2007) discussed the fact that these issues are more challenging under Web 2.0 than with Web 1.0.

[10] http://www.freedomscientific.com/Products/Blindness/JAWS
[11] https://help.gnome.org/users/orca/stable/
[12] http://www.yourdolphin.com/productdetail.asp?id=5
[13] http://www.gwmicro.com/Window-Eyes/

With Web 2.0, end users became co-authors; for example, on blogging and social network websites. These authors may or may not be aware, let alone knowledgeable, about web accessibility challenges. Therefore, accessibility cannot be guaranteed (Kern, 2008).

2.8.3 Web Accessibility Evaluation

There are various means and methods of evaluating web accessibility; some of which are fully reliant on investigating the conformance to guidelines and others of which employ or are influenced by usability evaluation approaches (Brajnik, 2006). Evaluation methods that investigate the conformance to guidelines are the most widely used approaches; they can either be automated or conducted by a human evaluator (Vigo et al., 2013). Fully automated approaches are carried out by dedicated software tools that examine the HTML code's conformance to a set of guidelines. The W3C's website outlines a set of tools that can be used. The reliability and completeness of these approaches have been strongly criticized (Ivory and Chevarlier, 2002; Vigo et al., 2013).

Manually inspecting a website's conformance to accessibility guidelines by a human evaluator is another approach. This approach is called conformance, expert, standards or guidelines review. The evaluator could be an expert or novice and it could involve one or more evaluators. The process can involve software support, and the degree of inspection can differ depending on the requirements of the evaluation (Rutter et al. 2006). Using this approach, the evaluator manually checks whether a webpage satisfies the set of guidelines. The assessment is highly dependent on the evaluator's judgment, therefore the evaluator effect has been highlighted as a shortcoming of this approach (Petrie and Khier, 2007; Brajnik et al, 2010). To overcome the shortcomings of both methods, usually a combination of approaches is performed as certain issues are best addressed by certain evaluation methods (e.g. (Takagi et al., 2007)).

Researchers have argued that examining the conformance to accessibility guidelines is not enough to insure the usability of webpages (Shneiderman, 2000; Hudson, 2004; Horton and Leventhal, 2008). A website may be compliant with accessibility guidelines, but may have many usability issues present which prevent users from effectively accessing the website

(Correnani et al., 2004). Hudson (2004) presented the results of a survey conducted by City University, London for the UK Disability Rights Commission which evaluated the accessibility of 1000 UK web sites. According to Hudson, more than 35% of the highlighted problems are actually usability issues. The paper concluded that there is a need to look at 'universal design principles' as a means to satisfying web accessibility. Like Hudson (2004), Power et al.'s (2012) study revealed that only 50.4% of web accessibility problems that blind users encountered were covered by WCAG 2.0. These studies asserted the role of usability in finding accessibility problems in webpages.

Nevertheless, the difference between accessibility and usability has been a source of debate (Petrie and Kheir, 2007). Many researchers have reached different conclusions: while Hudson (2004) defines accessibility to be a 'prerequisite' to usability, Thatcher et al (2003) describe it as a subset of usability. Shneiderman, on the other hand, referred to both concepts as 'universal usability'. Despite the differences in the descriptions of the nature of the relations between the two concepts, it is quite clear that accessibility needs usability to fulfil its goals. Information may be accessible but if users are unable to use it then the goal of accessibility is not met.

Usability testing approaches have been adapted as empirical methods in studies that have evaluated the accessibility of websites (Jay et al., 2008). These approaches usually involve members of the target user population taking part in the evaluation process. Methods such as Think-aloud protocols (Lewis, 1982) have been used to investigate accessibility of websites for blind users (Power et al., 2012; Petrie and Kheir, 2007; Mankoff et al., 2005). Heuristic evaluation (Nielson and Molich, 1990) has been used in an accessibility inspection (Paddison and Englefield, 2003). According to the authors, accessibility heuristics can address accessibility problems more effectively than guideline-based reviews. However they emphasise that their approach does not replace the guidelines review, which is still required by legalisation.

In an attempt to address the gap between guidelines review and usability evaluation, Brajnik (2006) presented the barriers walkthrough approach, a method based on Sears's (1997) heuristic walkthrough. Using the barriers walkthrough approach, an evaluator has to consider a number of predefined possible barriers which are interpretations of the WCAG guidelines. The barrier is an accessibility condition that hinders a user from performing a task in a specific context. The context comprises the target user group, the scenarios or webpages being accessed by assistive technology tools and the user's goals in each scenario. Brajnik (2006) grouped the barriers into categories according to the context.

In contextual design the users' need and their environment are the focal source of information and the base for the interface design. The contextual approach has been considered in a number of studies concerning inclusive design. One such work is by Akoumianakis and Stephanidis (2003) who introduced a contextual scenario-based approach to serve this purpose. Sloan et al (2006) have explored the contextual concept by introducing a holistic framework to guide web authors and policy makers when considering accessibility. The framework shows that accessibility issues can't be solved solely outside of their context, which includes the user needs, the technologies employed and most importantly the tasks to be achieved. Moreover, it highlights the shortcomings of the W3C guidelines. From a user perspective, Vigo et al. (2007) presented a framework accompanied by a tool to evaluate the accessibility of a webpage depending on its context. The user-tailored tool evaluated the webpage coverage of the guidelines that are strictly related to the context (i.e. the user group, the assistive technology and the task). The outcome of the evaluation is an accessibility report that provides the user with an insight into a webpage's degree of accessibility. The aim of the framework is to produce a personalized evaluation process in order to improve user's experience on the web.

2.8.4 Accessible Information Seeking

Despite the fact that the issue of web accessibility has, and continues to receive increasing attention both in research and in the commercial world, led by the W3C initiatives toward web accessibility, the area of accessible information seeking, as opposed to web accessibility, has been rarely examined (Sahib et al., 2012). The sequential nature of screen readers imposes many challenges on VI information seekers. These challenges range from the total loss of context to the overloading of short-term memory.

Studies have highlighted these challenges and proposed a set of guidelines to be considered when designing an accessible search engine (Andronico et al., 2006; Craven and Brophy, 2003). While these studies focused on the usability aspects of the problem, a study by Ivory et al. (2004) observed blind users' information seeking behaviour. The result showed that blind users often rely on certain factors to judge the relevance of a page. Other than the page's summary and title, the number of adverts and words are also often considered. The study suggests that the complexity of a webpage being accessed as part of a search can have a huge impact on the decision concerning whether or not to explore that web search result.

A more recent study by Sahib et al. (2012) attempted to identify the challenges faced by VI information seekers during the different stages of the IS process. In the comparative analysis of Sahib et al. (2012), an observational user study was conducted with 15 VI and 15 sighted participants. The participants were asked to perform a complex task which required a high level of cognitive effort (e.g., planning a vacation). The results of their comparative study identified major differences between the information seeking behaviour of VI and sighted participants. These differences were more apparent in the query formation and results exploration stages. The inaccessibility of query-level support features for screen reader users was one of the main barriers highlighted in the query formation phase. VI participants were either unaware of the features or simply avoided using them as they found them hard to use. In the search exploration stage, the study observations indicate that the VI participants spent more time exploring the results. Additionally, the number of results viewed by VI participants was considerably lower than the number of results viewed by sighted participants. Their findings led to the development and evaluation of a search interface that aimed to tackle the issues identified (Sahib et al, 2015). In the search interface developed they introduced an accessible spelling support feature using non-speech sound and provided users with features to track and manage previous search results. The newly introduced features were well received by VI participants, which emphasised the role of usability design and enhanced users' experience.

2.8.5 The Use of Sound in the Web

The previous sections addressed web accessibility using traditional assistive technology tools (e.g. screen readers). This section examines the relatively moderate amount of research addressing the use of sound on the web. It starts by providing an overview of the main techniques in representing sound in auditory displays. It then reviews the research efforts that utilize auditory display techniques to enhance VI web browsing.

In the area of auditory displays, apart from synthesized or recorded speech, researchers have focused on three techniques to represent data: auditory icons, earcons and spearcons (Peres et al., 2008). Auditory icons, which were introduced by Gaver (1986), are ‘everyday sounds mapped to computer events’. They are used metaphorically in the same way in which icons are used in a graphical user interface. In fact, many examples of them are used in graphical user interfaces, such as the tapping sound that is heard when a file is selected (Gaver, 1986). Users can directly and intuitively relate them to their functionality without the need of training (Peres et al, 2008). In comparison to auditory icons, earcons are more symbolic and abstract (Blattner, 1989). Earcons are built from musical motifs, defined by Blattner et al (1989) as ‘rhythmic sequences of pitches’. Each collection of motifs forms an earcon, thus allowing earcons to inherit properties from other earcons, which is in part why they are so powerful. Blattner et al (1989) have employed icon design principles to design earcons, due to their assumption that earcons are the audio equivalents of icons. Brewster (1996) have examined their use in representing hierarchical structures of data. As an outcome of their study they provided a set of guidelines which could be considered in the design of earcons to represent a hierarchical structure.

Spearcons were first introduced by Walker et al (2006). They are created by speeding up speech to the extent that listeners will not be able to recognise the words in the spearcon but will be able to recognise the overall envelope of the sound, so that each item designated by a specific spearcon sound, typically a menu item, can be recognised. In a comparative study with auditory icons and earcons by Walker et. al (2006), it was proven that the use of spearcons for menu navigation improved performance.

Research investigating the use of auditory display techniques for web interaction has mainly focused on overcoming the difficulties that VI users encounter while browsing the web using a screen reader. Given the sequential nature of a screen reader's output, browsing a webpage can be a frustrating task (Lazar et al., 2007). The amount of information rendered can overload the user's short-term memory (Murphy et al., 2007a). That is in addition to the complete loss of spatial layout and textual attributes of a webpage, which can bear essential information to the user (Correani et al., 2004).

To overcome these barriers studies have aimed to preserve the structure and layout of web documents. They have sought to overcome the information overload issue by using non-speech auditory display techniques. Research that employed the use of auditory display techniques in the web has either looked into preserving the webpage structure and aiding the navigation process or investigated ways of providing an audio overview of the webpage. The subsequent sections will discuss these studies.

Representation of Structures in the Web

There are a number of papers presented in the International Community of Auditory Display (ICAD) conference series that endeavour to preserve the document structure given the linear nature of speech. Susini et al. (2002) suggested the use of non-speech sound to be played prior to encountering a hyperlink to allow VI users to identify its presence. The results of their study showed that adding a 'sonified hyperlink' improves VI users' performance and hence less time is spent navigating webpages. HearSay (Borodin et al., 2007), a research project at Stony Brook University that aims to build a non-visual directed browser, also explored the use of Earcons to distinguish between different page contents.

While Susini et al. (2002) and Borodin et al. (2007) looked into using a single technique in rendering context on the web, James (1997) proposed using a combination of speech, auditory icons and earcons in representing the structure of an HTML document. The investigation illustrated that such a combination can noticeably improve users' performance. On the other hand, Petrucci et al. (2000) and Goose and Moller (1999) proposed that in addition to the use of auditory icons and earcons there is a need to convey object location on a webpage using 3D spatial sound.

Representation of Overviews on the Web

In an empirical investigation into challenges faced by VI users when browsing the web, one of the main findings was the need for an overview of a webpage (Murphy et al., 2007b). The study involved 30 blind and partially sighted users. The majority of participants stressed that getting an overview of a large amount of information when using a screen reader is extremely difficult and imposes a significant cognitive demand.

In the late 1990s Shneiderman (1996) introduced his well-known information seeking mantra: ‘overview first, zoom and filter, then information on demand’ (Shneiderman, 1996). This principle, mainly targeting visual environments, emphasized the importance of overviews in developing the user’s understanding of the context of information. Zhao et al. (2004) (Zhao being at that time a PhD student in Shneiderman’s lab), extended this principle further by presenting its applicability in the field of auditory interfaces. Following the same pattern of Shneiderman’s (1996) mantra they proposed the Auditory Information Seeking Principle, which is ‘Gist first, navigate, filter then details on demand’. In this principle, ‘gist’ refers to a short sound message which gives the users an overall idea about the context of the data (Zhao et al., 2004; Zhao, 2006). Several researchers have applied this principle to different applications. Kildal and Brewster (2006) examined providing an overview of tabular data using sonification techniques. Nickerson and Stockman (2005) used overviews to provide VI users with overall information about the desktop interface in an attempt to improve navigation.

In the context of web browsing, Zajicek et al. (1998), Parente (2003), and Harper and Patel (2005) introduced the idea of providing a summary of a webpage to VI users before navigating to it. While Zajicek et al. (1998) and Harper and Patel (2005) benefited from the body of knowledge in IR to develop algorithms that summarise webpages, Parente (2003) based his work on the Agileviews framework (Marchionini et al., 2000). The Agileviews framework suggests that in order for a user to have an option of where to focus during information seeking, the user needs to have access to information from different levels, including overviews, previews, reviews, peripheral views and shared views. Parente (2003) provided speech-based previews of links that contained basic statistical measures and the main structure of the target page. All three studies used speech to communicate the summary to users. None examined the use of non-speech sound. However they concluded that the availability of an abstract of a webpage enables a faster browsing rate and hence enhances user performance when browsing large volumes of web search results.

Commercially few attempts have been made to facilitate the overview feature for VI web surfers. Some examples of screen readers that do implement this feature are JAWS, Window-Eyes and Apple Voiceover[14]. JAWS and Window-Eyes have a dedicated keyboard command that when pressed provides the users with the number of links, headers, forms and frames in the current webpage. Voiceover provides an interactive overview of webpages using a mechanism called the web rotor. Here users select a specific element type such as header or form, and then rapidly navigate sequentially forwards or backwards through elements of that type, navigating to instances of specific interest. Moreover the W3C's WAI-ARIA provides a way for screen readers (e.g. JAWS and Window-Eyes) to convey an overview of a webpage layout (Craige et al., 2010).

2.9 Cross-Modal Collaborative Interfaces

This section starts by discussing two studies that aim to provide general guidelines and principles in designing cross-modal interfaces. This is followed by a small number of studies that examine the applicability of a cross-modal interface in performing different tasks. The section concludes with examining literature on cross-modal collaborative web use.

[14] http://www.apple.com/uk/accessibility/ios/voiceover/

2.9.1 Cross-modal Interfaces

Mynatt (1995) made one of the earliest attempts to establish standardized guidelines and principles in this area. She investigated the provision of additional modalities to graphical user interfaces (GUI) in an attempt to overcome accessibility barriers in a Windows-based application. Following Mynatt's generalized attempt, Bangor and Miller (2008) discussed multi-modal interface design from a HCI viewpoint by specifying general guidelines in addition to recommending testing and evaluation methodologies. In their work they looked at the general problem of multimodal interface design and did not specifically target participants with special needs. In other words, they discussed multimodal interfaces but not cross-modal interfaces. However they briefly discussed the potential of cross-modal interfaces in facilitating collaborative work. They strongly recommended the adoption of a user-centric design approach when developing complex interfaces with multiple modalities as a designer can tend to be less focused on the target user group in this situation. Contrasting this Winberg (2006) emphasized that the designer’s knowledge of the context of use in interaction design is a crucial factor. There are a small number of studies in which the applicability of a cross-modal interface concept was examined and each will be briefly discussed below:

Winberg (2006)

In a study of drag-and-drop-based collaboration by Winberg (2006), two participants were asked to collaboratively work together to arrange a number of objects in a grid. The experiment involved one sighted participant using a visual interface and one VI participant using an auditory interface. The outcomes of the experiment indicated that the interface allowed the VI participant to effectively participate in the problem solving process. Moreover, it was observed that both participants worked equally in performing the required task, demonstrating the value of designing the tasks for effective collaborative interaction.

McGookin and Brewster (2007)

McGookin and Brewster (2007) also employed haptic, speech and non-speech sound to support collaboration between VI and sighted users when accessing and manipulating bar graphs. Their work examined the use of audio and haptic output in allowing users to be aware of other users' activities in a collaborative interface. Their findings indicate that shared haptic and audio output can potentially aid the collaboration process. However more investigation is required to support the applicability of the findings.

Plimmer et al. (2008)

Plimmer et al. (2008) introduced a multimodal collaborative tool to be used in teaching and learning environments that facilitated the process of drawing alphabet letters shapes for VI children. The tool used the PHANTOM omni haptic device accompanied by audio cues to guide VI children in following teachers' drawings and hence allowing them to learn and replicate the movements. An evaluation of the tool with several VI students produced satisfactory performance and also increased the enjoyment and level of excitement during the learning process.

Metatla et al. (2008) and (2012)

Metatla et al. (2008) implemented and evaluated a prototype that allows users to navigate and edit node-and-link diagrams using a cross-modal combination of visual and audio interaction. The information communicated through an auditory interface consists of contextual information, navigational feedback, and the contents of nodes and links. Initial laboratory testing yielded promising results, which indicated the possibility of employing the interface in a real-world scenario (Bryan-kinns et al, 2010). A following study by the same group evaluated auditory and haptic collaborative diagram editing tools with sighted and VI co-workers in their workplace (Metatla et al, 2012). A set of initial recommendations informing the design of interfaces that support cross-modal collaboration was produced.

Al-Thani and Stockman (2010)

Another study was conducted to develop and evaluate a cross-modal XML schema browser. The aim of this study was to explore usability barriers when VI and sighted users work collaboratively using an interface with audio and visual cues (Al-Thani and Stockman, 2010). The project also considered the limited view experienced when using small screen devices such as personal digital assistants (PDAs). The auditory interface of the browser employed auditory icons, earcons, and synthethic speech to represent multi-level navigation within an XML-schema browser. Usability-centred evaluation experiments were carried out to assess the ability of the cross-modal interface to support collaboration. The results of the experiments showed that the interface assisted the participants to work efficiently and equally in completing the given tasks. In fact the results showed that the time taken by VI users to complete a task using the auditory interface was nearly half the time spent using a traditional screen reader. This illustrates the benefit of using non-speech sound techniques to improve the bandwidth of human-computer communication.

It can be deduced from the literature discussed above that we are still far away from introducing general guidelines and methodologies when designing cross-modal interfaces. In fact the field can be considered in its initial phases, with only a small number of promising studies that explore the field in depth.

2.9.2 Cross-Modal Interaction on the Web

As discussed, the research in the field of cross-modal interfaces is fairly limited. Nevertheless, studies examining collaborative web use between sighted and VI users highlighted challenges that includes screen readers' inability to convey structure, spatial location and context to VI users. These problems are exacerbated by the absence of an overview and the short-term memory overload that screen readers impose on their users (Stockman and Metatla, 2008). These barriers can certainly enforce a sense of frustration on the VI user when collaborating with their sighted colleagues (Lazar et al., 2006). There were a number of studies intended to tackle these barriers for a single user scenario, which has been discussed in section 2.8.4. However their applicability in a collaborative environment was never examined. We shall briefly revisit these studies below within the context of collaboration.

Murphy et al. (2007b) studied the provision of audio and haptic feedback to users in an attempt to eliminate the differences in VI and sighted users' mental models of spatial navigation within a webpage. In this study a multimodal browser plugin was developed. The browser conveys spatial location using both auditory icons and a force feedback mouse. The experiments required pairs of VI and sighted users to collaboratively perform a task. The task was designed so that the VI user must be guided by the sighted user to perform a task, where the sighted user is describing the spatial location of an object on the page and the VI user uses this description to locate the object. The results of the experiment showed that the use of auditory icons can improve VI users' cognition of spatial location, thus assisting VI users in developing a mental model of the page layout that is consistent with the sighted user's mental model.

A study by Stockman and Metatla (2008) argued the fact that more issues need to be addressed in order to overcome barriers to collaboration during cross-modal web interaction. They conducted a survey and a task-based study to examine the differences in users' perceptions of web sites and to identify the obstacles faced by VI users when performing collaborative tasks with sighted users. They identified a set of barriers that demonstrate the magnitude of the differences between VI users and sighted users' mental models of webpages. The identification of these barriers led them to propose a taxonomy of human error in cross-modal collaboration. The taxonomy introduces nine categories of error. Some of these categories have been highlighted in texts mentioned in previous sections of this background study and include different mental models of spatial location, layout, context and navigation. Furthermore they pointed out the importance of maintaining the affordance characteristics across different modalities of a system. The taxonomy also identifies that there is a lack of sufficient information provided to the user to create a holistic view of a webpage, despite some screen readers' attempts to offer their users page overviews. They concluded their study by discussing the potential benefits that incorporating knowledge from auditory displays can provide in resolving the limitations of currently used screen readers.

2.10 Chapter Summary

In this chapter we have discussed specific background information from different research areas for their relevance to the work presented in this thesis. The chapter starts with outlining previous information seeking theories and models, as information seeking is the core process of CIS. That is in addition to the fact that the work in Chapter 5 benefits directly from the study of Marchionini and White (2008) in understanding the process of information seeking both individually and collaboratively. We then describe the previous work done in the field of CIS, starting with definitions and models in section 2.4. This was followed by a discussion of the work done to date in examining the different CIS concepts in section 2.5 and dimensions in section 2.6. We then reviewed work done in relation to the evaluation of different aspects of CIS in section 2.7. Web accessibility was then explored in section 2.8. While this thesis is not primarily concerned with single-user web accessibility, a study of CCIS cannot be completely separated from these issues and so it is covered here as relevant background and is revisited at relevant points during the studies described in later chapters. We conclude this chapter by reviewing the area of cross-modal interaction in section 2.9. In Chapter 3, we describe the overall methodology adopted. We discuss the main research methods employed and the instruments used. We also detail the data collection and analysis as well as sampling criteria and ethical considerations employed in the rest of the thesis.

Chapter 3 Methodology

3.1 Introduction

In this chapter we discuss the overall methodology of the thesis. Section 3.2 starts by describing the approach taken; Section 3.3 presents an outline of the studies conducted; Section 3.4 looks into the main research methods used. This is followed by descriptions of the user study design in section 3.5. The instruments for the user studies are discussed, including a justification of the task choices made in the user observational studies and in the accessibility review in section 3.6. A description and justification is provided of the methods used to gather data in section 3.7. Finally we detail qualitative and quantitative approaches used to analyse the gathered data in section 3.8. This chapter concludes with a discussion of the participant sampling criteria in section 3.9 and the participant recruitment process and ethical considerations in section 3.10.

3.2 Overview of Approach Taken

User studies are an empirical method commonly used in HCI to understand users' needs and behaviour, and evaluate a situation in which technology is used. In such studies, quantitative methods are frequently employed to collect and analyse data in numerical form. The analysis of this data is often related to hypothesis testing and provides a basis for comparison between groups and/or between interactions performed under different conditions (MacKenzie, 2013). Qualitative methods have also long played an essential role in these types of studies (Suchman, 1987). They are increasingly being employed in the field of HCI as they provide holistic views situations and therefore support the researcher in perceiving the issues and patterns which occur.

In this thesis we are exploring the interaction between VI and sighted users conducting collaborative web searches. This is the first study we are aware of in this area, and so it is by definition exploratory. We are interested in quantitative measures (for example in order to make comparisons between CCIS activities in different conditions), but we are also interested in the collaborative process and user experience, a full picture of which requires a combination of quantitative and qualitative measures. Therefore we conducted semi-structured qualitative studies that involve questionnaires, observational studies and interviews. Semi-structured qualitative studies mainly focus on developing an understanding of a situation in an exploratory way (Blanford, 2013). There is also some structure to the process of analysis that includes systematic coding of data, which is quantitative in nature. The method also considers quantitative data which is crucial to the analytical process. The user studies we designed collected both qualitative and quantitative data. Qualitative methods such as the structured observations and semi-structured interviews allowed us to understand the process of collaboration and the behaviour of users during the CIS process. Quantitative data, such as duration of a given information seeking stage, query term length, number of search results explored and stored etc. represent t essential measures to understand the process. This broad combination of data provides an in-depth view of CCIS activities performed under different conditions, and so provides a basis for understanding the process and developing a rationale for how to better support and enhance it.

3.3 Outline of the Work Done

There follows an outline of the main stages of the work.

Preliminary survey

We conducted a preliminary online questionnaire that captured VI and sighted individuals' personal search results and management habits. It also investigated how often CCIS activities occur between VI and sighted web users. This initial survey helped us to identify how frequently CCIS activity occurs. It provided us with an insight into the nature of the process and so underpinned the experimental design of the first study.

Study 1

We conducted an exploratory observational study that investigated the challenges faced and behaviour patterns that occur in CCIS activity between 14 pairs of VI and sighted users (described in Chapter 5). In this study participants used their tools of choice, that is their preferred web browser, note taker and communications system. We observed behaviour patterns that occurred in CCIS activities in both co-located and distributed settings. The study explored issues such as awareness, division of labour and results management in the presence of cross-modality. The study also looked at how the different stages of information seeking were performed. This study allowed us to develop an understanding of different aspects of the CIS process in the context of cross-modality, and the influence of cross-modal interaction on the different stages of the process.

A follow-up to study 1

Following study 1 we carried out scenario-based interviews with seven VI and seven sighted users who were involved in study 1. These interviews investigated their web search results management habits to deepen our understanding of the results of the exploratory study and to further explore the results management stage. The study provides an insight into how users retrieved information, the technologies used and the differences in the ways that VI and sighted users manage retrieved information. The outcome of study 1 with these additional interviews yielded results which allowed us to form an understanding of the CCIS process when employing the users' tools of choice, without the use of any system specifically supporting the collaborative process. The understanding gained from this first observational study and the follow-on interviews enabled us to compile a set of design recommendations for CCIS systems features.

Functionality and accessibility review

Having examined the CCIS process in the absence of any specific system to support it, the questions we then wished to pursue were; "Can the CCIS process benefit from some of the advantages that mainstream CIS activity obtains through such a system? (Morris and Horvitz, 2007a) And to what extent can some of the difficulties seen in the first observational study due to this lack of support be addressed by the introduction of such a system?" Given the time and resource constraints of the PhD, it was not a feasible option to develop and evaluate a system to support CCIS from the ground up. Such systems are large and complex and take many man-years to develop.

Thus the purpose of the next stage then became to identify candidate systems that might be used to explore the questions. There was of course no guarantee that any such system would exist. The investigation consisted of three stages; firstly, the available mainstream CIS systems were surveyed to choose the ones that were both available and suitable in their coverage of the CIS process. The features and functionalities of the chosen systems were then mapped to the design features from Study1. This was followed by a task-based accessibility assessment; the final choice of the system to be used was based on the outcome of this final stage. The outcome was that there was no single system which was sufficiently accessible as it stood. However there was one system that was close enough that sufficient improvements to its accessibility could be made within a suitable timescale in order for it to be employed in a study to address the research questions. The next stage of the project involved developing and testing the required improvements to this system's accessibility. At the end of this process we had an extended tool which was sufficiently accessible for use in a study to address the research questions we wished to explore.

Study 2

Study 2 is an observational study that explores CCIS behaviour between VI and sighted users using the extended CIS tool in both co-located and distributed settings. This study was carried out with the same 14 pairs of participants that took part in study 1. The overall aim was to understand the changes in behaviour, process and challenges when a mainstream CIS tool with extended accessibility features is specifically introduced to support the CCIS process. Areas of particular interest included performance, workspace awareness, information made available, division of labour and, stages of the information seeking process. Quantitative and qualitative data were collected and the findings analysed and compared with the results of study 1. The final stage of the process was to produce a set of recommendations towards the inclusive design of a tool to support CCIS.

3.4 Methods

In the two studies mentioned in section 3.1, four empirical methods were used. We provide a brief description of each method below:

User observational study

In Studies 1 and 2 we observed users undertaking structured CIS tasks in pairs, with the pairs comprising one VI and one sighted participant. In structured observations researchers direct the participant[s] to perform certain activities. In other words, the researcher sets the scene and then observes users' actions accordingly, as the objective is to investigate a specific behaviour (Wilson and MacLean, 2010). In our 2 studies participants are given a search task to complete collaboratively; section 3.6.1 provides more details about the search task. Following the task, we conducted a semi-structured interview with each participant to discuss the issues encountered while performing the task. Interviews are best suited to understand people's perception of a situation and provide an opportunity for the researcher to explore people's experience in more detail (Flick, 2009, p. 222).

Scenario-based interviews

The findings of study 1 reveal there were clear collaboration issues that appeared in the information seeking process which are the result of the exploration and management stages. To further explore some of the results related to retrieved information management, we decided to interview seven VI and seven sighted participants who participated in study 1. Chapter 6 describes the scenario-based interviews. The scenarios were used to describe a situation involving CIS which provided a context for participants to discuss events in the CIS process, and to describe resulting actions. This type of interview helps engage participants through the use of storytelling approaches, and hence provides an understanding of the interactions people describe (Carroll, 2000). This type of scenario or narrative approach is widely used for requirements gathering (Rogers et al., 2011).

Accessibility review

To choose the most eligible software package for VI and sighted users to perform CCIS tasks, we determined the accessibility of possible candidate systems. The purpose of this review was not only to examine the accessibility of the systems, but also their usability. The approach used in Chapter 7 was informed by the Barrier Walkthrough approach (Brajnik, 2006), which specifies a set of pre-determined barriers that the evaluator looks for. The approach is an adaption of a usability heuristic walkthrough method (Sears, 1997). Chapter 7 describes in detail how we employed this method to perform the accessibility review.

Usability evaluation

Measuring the effectiveness of the interface has been the focus of the majority of studies in the field of CIS (Shah, 2014). It is evident from the literature that the purpose of performing such user studies on new CIS systems may vary. For instance, while some studies aim to identify the features users preferred (Amershi and Morris, 2008), other studies explore the impact of the interface on the tasks performed (Gonzalez-Ibanez et al., 2013). In study 2 a number of usability inspection measures (Nielsen, 1994) were used to evaluate the users' interaction with the interface. This helped in identifying the patterns and frequencies with which the features were used, the accessibility issues encountered, and the impact these had on the process of CCIS.

3.5 Study Design

All the participants who took part in study 1 were recruited to take part in study 2. The reason for recruiting the same participants is solely related to the research questions in study 2 that investigate the effects of the interface on the different concepts of CIS and the IS behaviour of the participants. Using the same participants had the benefit of allowing us to compare the performance of teams and their level of engagement with the CIS tasks in both studies. This in turn enabled us to examine the effects of the interface used in study 2, including the extent to which it supported CCIS activity. Using different participants in each study would have resulted in more variability due to individual differences, and would have provided us with no bases for comparison. When examining the influence of different interfaces with participants performing similar tasks, experiments in HCI tend to favour using the same participants rather than using different participants (MacKenzie, 2013, pp 175-177).

In studies 1 and 2 we followed the same within participant design. In the studies each pair of participants performed the tasks under two conditions (co-located and distributed). One task was performed in a co-located setting and the other task was performed in a distributed setting. The main reason for choosing this approach is to lessen the impact of individual differences and to see how behaviour patterns and performance varies across conditions for each pair. It is important to ensure that the order in which participants perform tasks does not bias the results (MacKenzie, 2013, p. 177). To minimize order effects care was taken in the studies to counterbalance the order of the tasks. In each study, seven pairs worked in the co-located condition followed by the distributed condition; while the other seven pairs started with the distributed condition followed by the co-located condition.

3.6 Instruments

3.6.1 Search Tasks in the User Observational Studies

Bruce et al. (2003) affirmed that the nature of the task in terms of its structure and context is an important factor that can influence collaborative behaviour. Surveys have revealed that simple information look-ups and fact finding tasks do not benefit from CIS activity, but an exploratory search task is likely to benefit from CIS (London, 1995; Morris and Horvitz, 2007a). In the design of the exploratory tasks used in this study, we have been influenced by (Kules and Capra, 2008), who reviewed the literature and analysed large log files of search data, and outlined a set of characteristics that designed exploratory tasks need to fulfil. The characteristics include: the need to discover, the lack of prior knowledge, a situation that participants can relate to their context and a topic which is of interest to the participants.

In an early pilot of the experimental design of study 1 pairs were asked to organize a workshop in a venue near the university where they worked. The study did not go as expected and the participants rarely performed information seeking tasks during the session. The participants (a university lecturer and a postgraduate student), were very familiar with the area and hence relied on their prior knowledge in organizing the work, and the task was trivial for them. They depended entirely on their prior knowledge, which greatly reduced the complexity of the search task and hence affected their search behaviour (Bystrom and Jarvelin, 1995). The task was substantially modified following the pilot study to try to ensure participants would have to perform a substantial exploratory search. The task involved asking participants to work collaboratively to organize a business trip or plan a vacation. They were given dates of work engagements in three different cities. They were asked to organize travel, accommodation and activities in these cities. In advance of each study we made sure that participants had not visited the cities before. We were clear in our wording that the participant was not asked to "*actually make the booking but [they] needed to take notes of all details that would help [them] both in making the actual booking later in time".* The tasks were slightly modified to match the workplace context of each pair. For instance, if the participants worked in academia the context of the business trip would be related to academia, such as attending a conference and organizing a workshop in a university. Examples of the tasks can be found in Appendix B.3.

We designed four tasks, one for each condition in each study. All four tasks are equivalent in terms of structure and the number of items of information required to be retrieved. Two tasks were designed for each study. In study 1 participants were asked to work collaboratively to organize a trip to the United States in the co-located condition, and a trip to Australia in the distributed setting. Each trip involved visiting three cities with activities to do in each city. In study 2, participants were asked to organize a trip involving three cities in the Middle East in the co-located condition task and three cities in Italy for the distributed condition task. The only modification was to the context of the tasks and not the amount of information to be found. This included changing cities and the activities to be arranged in each city. The number of activities that needed to be organized is equal across all tasks in both studies. Each task contained 13 sub-tasks; in other words, participants needed to perform 13 exploratory searches in order for them to complete the task. The sub-tasks across the activities were fairly equal in terms of the level of complexity; in which participants would need to search for a specific piece of information (i.e. information about hotel, travel or venue booking).

3.6.2 Tasks in the Accessibility Review

The tasks to be performed in the accessibility review were carefully chosen to cover all the scenarios that the user might encounter when performing CIS activities. The literature emphasizes the importance of this stage and its impact on the outcome of the review (Dumas and Redish, 1994). In usability studies tasks are often chosen according to a number of factors (Dumas and Redish, 1994, p. 160). This includes essential activities such as logging in and tasks that serve the purpose or goal of the user. The tasks involved all activities that occur in a CIS process employing a system dedicated to the CIS process including: accessing the interface and activating a shared workplace; performing the search; storing and managing retrieved information; using awareness features and communication tools. Additionally, tasks that probe potential usability or accessibility problems need to be considered. We classified the tasks into four categories according to the type of activity:

A. Tasks related to the login process and activating the project.

B. Tasks related to the results management process.

C. Tasks related to the individual information seeking process.

D. Tasks related to awareness issues in the process

Appendix C.1 and C.2 describe the tasks that belong to each category as well as the scenarios associated with each task.

3.6.3 Applications and Web Interfaces Used

In the user study described in Chapter 5 (study 1), we left the choice of applications used open to participants as the nature of the study was exploratory and the main objective was to understand the process and challenges when VI and sighted users search the web together. Participants were asked to use their own machines, their preferred web browser, and to choose a method to communicate with each other. For the accessibility review described in Chapter 7, the VI participants used IE and Firefox web browsers, JAWS version 12 and Nonvisual Desktop Access[15] (NVDA) version 2014.1 screen readers on the Windows 7 platform and the Safari web browser and Voiceover screen reader on iOS. For the final study described in chapter 8 users employed the extended CCIS system on their own machines. VI participants were specifically asked to use IE version 11 and JAWS version 12 or above in order to be compatible with the developed JAWS scripts.

3.7 Data Collection Techniques

Choosing suitable techniques to capture data is of great importance in observational studies. When observing a collaborative activity, the data needs to capture the participants' interactions with the applications they are using, as well as the participants' interactions with each other. In this thesis we use different methods of data gathering to fully understand the CCIS process. We used the following methods of data collection:

3.7.1 Questionnaires

Questionnaires were used three times in this thesis. They were used as a method to collect data online about CCIS activities in the preliminary study reported in Chapter 4. In study 1 questionnaires were used prior to the session to capture demographic information about the participants' search experience and proficiency, as well as the VI participants' use of access technology. In study 2 questionnaires were used post-study in order to collect data related to

[15] http://www.nvaccess.org/

accessibility and usability satisfaction levels. Participants were provided with digital questionnaires to complete.

3.7.2 Interviews

We used semi-structured and scenario-based interviews. The semi-structured interviews were used as a technique to gather further information in studies 1 and 2 following observation of the users performing the tasks. Semi-structured interviews provided a chance for the researcher to understand users' perceptions (Flick, 2009, p. 151). The semi-structured interviews were conducted individually with each participant to complement the data collected after each task in all studies. The aim of conducting these interviews differs in each study. While in study1 the aim is to allow us to discuss in detail the issues that arose during the collaboration, in study 2 we wanted to investigate in more detail the issues encountered while using the interface, as well as the issues related to communication and collaboration. We also asked participants their views about ways to enhance this type of collaborative activity.

In the follow-up to study 1 we used a scenario-based interview described in section 3.2. The interviewer would explain a scenario to the participants and ask the participants questions related to the scenario. The purpose of these scenario-based interviews was to further investigate specific results in study 1 related to retrieved information management.

3.7.3 Screen Recording

As Study 1 and Study 2 involved the use of existing interfaces for which we did not have the possibility to internally log user interactions, it was essential to record the participants' interactions with the interface. For this purpose we used the screen capture software Snagit[16] to record the participants' screens. The VI participants' screens were captured using a video camera, as we noticed in a pilot study that screen recording software can reduce the responsiveness of screen readers.

[16] https://www.techsmith.com/snagit.html

As a means of collecting data video recordings and screen captures, are time consuming and labour intensive and are often prone to selective attention and researcher bias (Kelly, 2009). Therefore prior to the data gathering process we predetermined the data that had to be recorded and transcribed. Following the studies it was necessary to view the video recordings of each session 3 times, as there were a large number of measures to be recorded. These ranged from measures related to the different stages of the IS process through to measures related to the use of specific system features.

3.7.4 Videotaping and Audio Recording

In the co-located setting in both study 1 and study 2 collaborators verbally discussed the tasks. The sessions were videotaped and the conversations were then transcribed by the researcher. Audio recording was used when interviewing participants in all studies; interviews were subsequently transcribed by the researcher. Participants gave their consent for all video and audio recording. Details of participant consent forms and the ways in which information was presented to them are discussed in section 3.9

3.8 Data Analysis

3.8.1 Data Coding

For each user study we transcribed the data and the conversations from screen recordings and the recorded videos. The screen recordings were annotated using a video annotation tool (ELAN4) to identify emerging patterns. The conversations from the videotaped sessions were manually transcribed by the researcher. In the case of the co-located setting participants communicated verbally, while in the distributed setting they communicated either using email or chat messages. We used Grounded Theory (Corbin and Strauss, 2008) to identify concepts from the recordings and to devise a coding scheme to identify common issues across different participants. Grounded Theory advocates for the theory to emerge from the data itself without any prior assumptions or preconceptions. Therefore it is useful for exploring complex relationships between concepts, such as the relationship between search interfaces, search tasks and the interaction between collaborators.

Grounded Theory consists of three stages of coding; open, axial, and selective (Corbin and Strauss, 2008). Open coding is the process of generating initial concepts from the data while axial coding is when the data is put together to establish connections between the different concepts and categories. The selective coding process includes the formalisation of the data into theoretical frameworks. The studies in this thesis, similar to (Makri et al., 2008) and (Sahib et al., 2012), seek to understand CCIS behaviour between visually impaired and sighted users and not to develop a new theory. Thus the selective coding stage was not conducted and the analysis was stopped after open and axial coding. The coding scheme captured three main aspects of CCIS: the process, the information exchanged and the use of information received.

***The process*:** coding schema included indicators of collaborative information seeking stages, information seeking processes, and occurrences of accessibility issues.

1. The stages of collaborative information seeking comprised an initial discussion phase followed by the collaborative search process:

2. The information seeking processes include: query formation, query reformulation, results exploration and results management. We used this coding approach to calculate the number of times each of these processes occurred across all pairs individually and collaboratively.

3. The different accessibility issues encountered by participants during the study, such as inaccessible web forms and webpages which presented navigational issues for screen reader users.

***The categories of the information exchange*:** coding schemes were identified during the coding process. However for the analysis of awareness information we have benefited from the framework developed by Gutwin and Greenberg (2002) which contains a set of elements relating to awareness information in collaborative activity. We have refined these elements so they fit the CIS process. The coding scheme we developed included the following categories:

1. Information to facilitate the division of labour, which can be further categorized into:

    - Initial division of tasks: This always happens at the start of the task, when participants divide the labour.

    - Reviewing outstanding tasks: This category occurs when the collaborators review work that has been done and identify outstanding sub-tasks.

    In study 2, additional sub-categories were introduced, such as organizing information in the shared workspace. This category occurs when collaborators discuss the way they will use the interface features to organize retrieved information.

2. Information related to the problem at hand.

3. Information to facilitate cross-modal collaboration, which can be further categorised into:

    - Requests for assistance by the VI participant in relation to a web accessibility issue.

    - Requests for assistance by the VI participant when viewing large amounts of information (e.g. search results).

4. Information to facilitate awareness: This category includes information about the status of the information seeking task (group awareness) or the status of the shared workspace (workspace awareness). This information can either be supplied or requested by a participant:

    - Information supplied: This can be further sub-categorised into the following; notifying completion of action, what I am doing and what I did.

- Information requested: This can be further sub-categorised into the following; what did you do, what you are doing, what you will do and did you complete.

The purpose of the received information coding scheme refers to the use of the received information by the participants. Four categories were identified:

- Category A: Information that is filed away by the receiver. This is information that is not immediately needed.
- Category B: Information that is needed but not critical. The receiver may use it in their next task but it is not t critical to completing the task.
- Category C: The receiver absolutely needs it for their next task. The receiver will not be able to complete a given task without it
- Category D: Information to avoid duplication of effort.

In addition to the above, in study 2 we captured usability and accessibility aspects of the interface. This included quantitative data about the use of the interface's four major components and their features, and qualitative data relating to the accessibility issues faced.

To insure the reliability of the coding scheme we provided guidelines to two independent coders which included guidelines about how to go about labelling each message. This included identifying the unrelated messages by "none". The coders were asked to independently code the collaborative sessions of two pairs in both the co-located and distributed settings. Cohen's Kappa measure revealed high levels of reliability with 1.0 for "the process" code scheme, 0.68 for the "information exchange" coding scheme and 0.76 for the "purpose of received information" coding scheme.

3.8.2 Statistical Testing

We used descriptive statistics and inferential statistics when analysing the quantitative data gathered from participants. Descriptive statistics are used to summarise a sample by examining the frequency and distribution of each variable. They are useful for identifying outliers and anomalies in the data (Kelly, 2009). In all user studies conducted in this thesis, we used descriptive statistics such as average, mode and standard deviation to describe the samples of participants and other quantitative data (such as query length and number of web search results explored). For a full list of measures in study 1 and study 2, see Appendix D.1.

In order for us to make inferences and draw conclusions from the available data sets we used both parametric and nonparametric statistical tests based on inferential statistics. A two-tailed paired sample t-test has been used to compare the information seeking behaviour of participants between conditions in the studies. We conducted a two-tailed unpaired sample t-test to examine the differences in information seeking behaviour between VI and sighted participants in study 1 and study 2. That is in addition to using a t-test with count data, for example, the use of specific interface features by VI and sighted participants. There is an ongoing debate in the HCI research literature on the consideration of count data (ratio-scale) measurement as a parametric or non-parametric data and thus the choice of which is the most appropriate statistical test. However there is a preference for parametric tests over non-parametric tests due to their statistical power (MacKenzie, 2012, p. 224). To insure the applicability of a parametric test such as the t-test on the count data, we checked the data for normalcy prior to performing the test using the D'Agostino-Pearson omnibus test (D'agostino et al., 1990)

In terms of non-parametric tests the chi-square test was used to analyse the information exchanged between collaborators in study 1 and study 2. It was also used to examine participants' access frequency to the different interface components in study 2. All statistical tests were performed at $p<0.05$ using the R statistical package[17].

3.9 Sampling

For the studies we chose to use purposive sampling, where the obtained samples must be chosen according to predetermined criteria (Wilson and MacLean, 2010, p. 163). The criterion for the

[17] http://www.r-project.org/

participants in the studies was that they must be experienced web users; this applied to both VI and sighted participants. Since we aimed to survey experienced web users, we advertised through specialised mailing lists. For the VI group we aimed to recruit participants with a minimum of five years' experience of using screen readers for study1. For participants who responded to our initial advertisement in the mailing list, we asked them to answer a short questionnaire that explored their experience with different screen readers and web-searching strategies. For study 2 we specifically needed experienced JAWS users, as the study required VI participants to use the JAWS screen reader. The JAWS screen reader is the most widely used screen reader worldwide (WebAIM, 2014), and all participants in study 1 had over 5 years' experience with JAWS. Thus they were also able to participate in study 2, which facilitated comparisons of the results between the two studies.

A similar questionnaire was also sent out to the sighted participants to ensure the appropriate level of web-search experience. Snowball sampling was also used in which a number of participants suggested other participants who they knew may be interested in participating in the study.

When it came to recruiting for study 2, 14 out of 16 pairs of participants agreed and were available to take part in both studies. Considering the numbers already used, data from the two pairs who did not take part in study 2 were omitted altogether from the results.

3.10 Recruitment and Ethical Considerations

14 pairs of participants were recruited in both studies. We recruited participants for the user studies mainly via online mailing lists such as the list for the British Computer Association of the Blind (BCAB) for the VI participants and through the School email list for PhD and Research students for the sighted participants. We also prompted VI users to bring a sighted person with them to perform the study. Four VI participants brought a sighted partner with them to the study. Participants were financially compensated with seven pounds per hour for taking part.

We received approval from the university's research ethics committee for all user studies in this thesis (QMREC2012/27). Participants were sent a detailed information sheet about the study so that they were aware of the implications and could make an informed decision about their participation. The information sheet explicitly stated that the sessions would be videotaped, the interviews would be audio recorded and their computer screen would be captured during the session. Participants were also asked to sign a consent form at the beginning of the session. All participants were informed that they could leave the study without giving any reasons and without any consequences for them. Participants were also assured that the data collected was confidential and would be stored in accordance with the Data Protection Act.

3.11 Chapter Summary

In this chapter we outlined the procedures used in the three studies that were carried out as part of this thesis, and we discussed the methodology employed in each study. We outlined the design, procedure and instruments for each study and discussed the methods of data gathering and analysis. We presented the data coding scheme used in study 1 and study 2.

Because we were not aware of any previous work done in the area of CCIS, in chapter 4 we describe how we conducted a preliminary online survey to examine whether CCIS activity goes on, and if, so how frequently it occurs.

Chapter 4 A Preliminary Survey: The CIS Practices of VI and Sighted users

4.1 Introduction

Web-based IS is frequently seen in both personal and professional settings. A range of web search engines are available to support this process. CIS is an emerging body of research that builds upon IS and CSCW-related work, as discussed in Chapter 2. This chapter describes a preliminary survey of VI and sighted users' engagement in CIS activities. The next section describes the reasons for conducting this survey.

4.2 Motivation

In section 2.9.2 we described previous studies which looked at VI and sighted users collaboratively browsing the internet. However the process of collaboratively searching the web has to date not been explored in the context of cross-modality. We determined to carry out a preliminary survey to examine whether - and how often - this activity actually takes place. This chapter describes the details of this survey, which was conducted online, and the results obtained. Part of the motivation for conducting the survey online was because online questionnaires have the potential to access groups that are typically under-represented in research (Skitka and Sargis, 2005). The questionnaire examines the frequency and characteristics of CIS activity between VI and sighted users. It explores the nature of the tasks performed, and investigates the tools used to support such activities.

4.3 Questionnaire Development

The questionnaire was divided into two major parts. The first part contained demographic and background-related questions (seven questions), and the second part investigated CIS behaviour (six questions). The purpose of the first part of the questionnaire, apart from collecting respondents' demographic data, was to know their level of visual impairment and the type of assistive technology they used. It was comprised of closed questions, apart from two questions where respondents were asked to provide their job title and details of the assistive technology they used. The second part contained questions relating to CIS. These questions explored respondents' involvement in collaborative searches, and the frequency of this activity. Moreover, it investigated tools and techniques used to communicate during this process; it also explored the type of tasks performed and the ways in which labour is divided between team members. The last question related to managing the retrieved results discovered during CIS activities.

4.4 Sampling

For this survey we chose to use purposive sampling, where the obtained samples must be chosen according to predetermined criteria (Wilson and MacLean, 2010, p. 165). The participants we were looking for were experienced visually impaired and sighted web users; both groups of users were surveyed separately. We surveyed them separately, as studies have shown that there are major individual differences in information management behaviour depending on the tools used, as well as the context and tasks performed. Moreover, earlier studies concerning IS by VI users revealed that they sometimes employ different strategies for managing retrieved information compared to sighted users (Sahib et al., 2012).

VI users were sent the questionnaire along with the survey cover letter and information sheet (available in appendix A) to IT-related mailing lists[18]. For sighted users we sent it to masters, PhD and research staff mailing lists at the Department of Electronic Engineering and Computer Science at Queen Marry University of London.

4.5 VI Respondents Results

The questionnaire received 31 responses from VI participants; 23 reached the final question and 12 respondents completed the whole questionnaire. For this questionnaire we chose not to omit the incomplete questionnaires as the answers to each question were analysed separately.

[18] http://www.whitestick.co.uk/mail.html

4.5.1 Demographics

16 of the VI respondents were male and 11 were female. The majority (12 male, 8 female) of VI respondents' ages ranged from 30 to 59. Table 4.1 summarizes the respondents' ages and gender.

Age range	Female	Male
18-20	0	1
21-29	1	2
30-39	3	4
40-49	2	4
50-59	3	4
60-older	2	1

Table 4.1 Number of respondents by age, group, and gender.

In terms of the level of visual impairment, 24 of the respondents were completely blind and three were partially sighted. In terms of their qualifications, 13 have a postgraduate or higher degree, while nine have an undergraduate degree, and the rest hold GCSEs or A-levels. 20 of those who answered the question about their occupation were employed; eight of these worked in IT (information technology), the remaining 12 worked in business, manufacturing or health services. 16 people responded to the question about length of employment. The majority of these (10), stated that they had been employed for over 10 years; two stated they had been working for two to five years; one stated he had been working for one to two years and three answered that they had been working for less than six months. As shown in Figure 4.1, all respondents indicated that they used a speech-based screen reader as their main assistive technology, while eight of them indicated that they also used a Braille display.

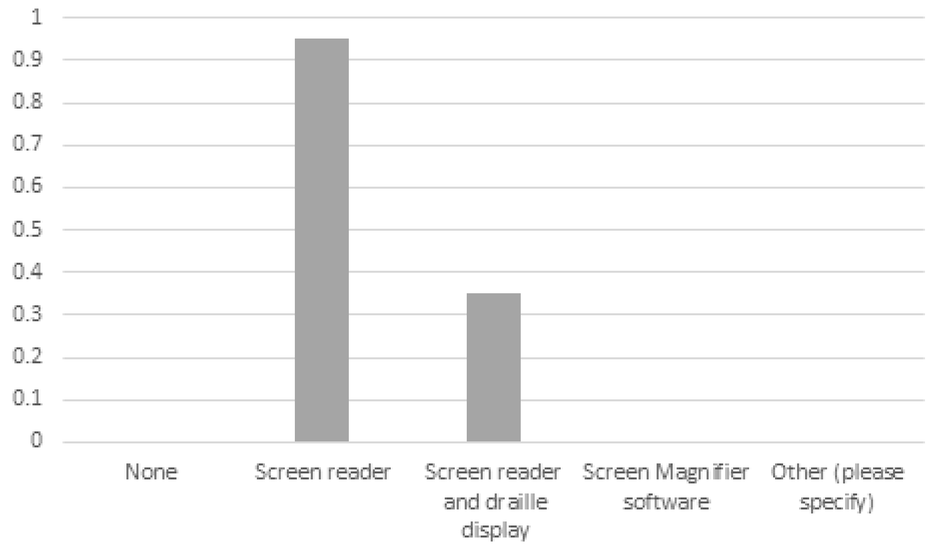

Figure 4.1 VI respondents' use of assistive technology.

4.5.2 CIS Results

This part of the questionnaire started by asking respondents whether they had ever been involved in a collaborative web search. 25 responded to this question; 14 respondents indicated that they get involved in joint web searches, while 11 said that they don't get involved in joint web searches. The next question examined the level of visual impairment of the people they worked with in collaborative search activities. Nine said that they usually worked with sighted and visually impaired people, whereas five said that they usually work with sighted people.

For respondents who indicated that they collaborate with visually impaired users in web searches, we asked them about the type of assistive technology the people they worked with used. Eight respondents answered this question; three respondents stated their VI partner used screen readers, screen magnifiers and specialised browsers; three others responded that screen readers are the only tools used by their partners with mainstream web browsers. Two respondents answered that they had only collaborated with people who used screen magnifiers with mainstream web browsers.

12 respondents answered the question about the frequency of collaborative search activity. Four respondents said they engage in collaborative search tasks at least once a month, while only two

said that it was a daily activity. Three stated that they did collaborative searches at least once a week, and the other three respondents indicated once a month.

The questionnaire then explored the CIS process by asking questions about the division of labour, communication methods, the ways retrieved results are managed and the type of search tasks engaged in. 14 responded to this question; 13 of respondents indicated that they do not tend to divide the responsibilities at the start of the search session; they said they tried to work and discuss each stage in the search process collaboratively. Only one respondent preferred dividing the work at the start into tasks and then discussing the results of each task.

16 respondents answered the question about the type of tasks they performed when carrying out CIS activities. Seven indicated that it was usually a task specific to them as an individual, such as planning a trip, shopping online or looking for medical information, while nine indicated that it was usually a work related task.

The most popular communication method employed during the CIS process was email, mentioned by 10 from 25 respondents who answered the communication tool question. The second most popular method was verbal communication, either via a voice call or face-to-face conversation (mentioned by eight respondents). Five respondents used instant messaging tools. Three respondents used shared folders or shared documents on the web to share search results. The least popular method was using a Braille print out, with only two respondents mentioning this.

For managing retrieved results respondents were given the option to select one or more approaches. 27 respondents answered the managing retrieved results related question. The majority (22 respondents) indicated that they use bookmarks and the favourites tool in a web browser. The second most popular answer (14 respondents) was sending links via email to themselves or to a collaborator. The third most popular answer (12 respondents) was saving the webpage into a folder and pasting the website link into a notepad or word processing document. (11 respondents) indicated that they pasted web links into a document. The two least mentioned approaches were taking notes about the search process (4 respondents) and printing the webpage (2 respondents).

4.6 Sighted Respondents Results

The questionnaire received 38 responses from sighted recipients, of which 28 reached the final question. 16 respondents fully completed the whole questionnaire.

4.6.1 Demographics

15 of the questionnaire respondents are female. The majority (23) of the sighted respondents' ages ranged from 21 to 29. Table 4.2 summarizes the respondents' ages and gender.

	Female	**Male**
18-20	2	1
21-29	11	8
30-39	1	13
Over 40	1	1

Table 4.2 Number of respondents by age, group, and gender.

23 were students at postgraduate level and 14 were employed or have work experience in academia, research or commercial companies. Six of the employed respondents have more than five years working experience. Since the targeted mailing lists were Masters and PhD candidates and research staff, it was not surprising that over 25 of the respondents already had postgraduate qualifications; the remaining 13 had an undergraduate degree and were already enrolled in a postgraduate degree.

4.6.2 CIS Results

16 out of 35 respondents indicated they get involved in CIS activities. 14 of them indicated that they only collaborated with sighted people, while two respondents stated that they collaborate

with visually impaired people who use screen readers. In terms of the frequency of this activity, 10 respondents answered this question; four respondents perform CIS at least once a month, while three performed CIS at least once in the past six months. The remaining three stated that they perform it on a daily basis.

The questionnaire then addressed the process of CIS. It asked about the division of labour, ways to increase the awareness and communication during the CIS activity and the ways retrieved information is managed. 16 respondents answered the question about the division of labour; eight of the respondents indicated that they usually divide the work before starting, while the other eight stated that they prefer to work together. 23 respondents answered the question about communication during the CIS activity; the most common way to communicate was direct conversation by either sitting together or through voice call. Nine respondents indicated this. This was followed by using emails and instant messaging, which was chosen by seven respondents. Six respondents said they updated shared documents, while one respondent used print outs of websites. When asked about the type of task they carry out when they perform a CIS activity; 26 respondents answered this question. 13 respondents indicated that it is mostly a personal task such as planning a trip, shopping online or looking for medical information; the other 13 respondents indicated that it is usually a work related task.

The most popular tool for managing retrieved information during a search process was bookmarks and the favourites feature in a web browser; 27 out of 35 respondents chose this. This was followed by emailing themselves and pasting links into a document; around 19 chose this. 13 of the respondents also chose keeping notes in a notepad or word processor document. The two least preferred choices were storing webpages in a folder; eight selected this, and four selected printing out webpages.

4.7 Discussion and Findings

The percentage of VI users who answered ‘Yes’ when asked about engaging in collaborative search activities was 56% (14 out of 25 respondents), which was quite a bit higher than the percentage of sighted respondents 45% (16 out of 35 respondents). Data from this study are consistent with numbers obtained by a Microsoft study (Morris, 2008) which investigated CIS behaviour in sighted users only. In the Microsoft study about 53.4% answered ‘Yes’ when asked if they performed collaborative searches. Five years later Morris (2013) reassessed the prevalence and frequency of users’ involvement in CIS activity. She surveyed 167 web users and found that the percentage of people involved in CIS activity was higher (65.3%), and with greater frequency. In Morris (2008) only 0.9% stated that they perform collaborative searches on a daily basis, but in Morris (2013) the number had increased to 11%.

There were differences in this study as VI and sighted respondents preferred to divide the labour while performing CIS tasks. While the majority of VI users 92% (13 out of 14 respondents) preferred working together throughout the process, only 50% (eight out of 16 respondents) of sighted users preferred working together, and the rest preferred dividing the work before starting the search.

In terms of the types of tasks being performed 50% (13 out of 26 respondents) of sighted respondents reported that the collaborative task was a business-oriented task, while 50% (13 out of 26 respondents) reported that the tasks were personal. The surveyed VI respondents reported similar numbers; 43% (Seven out of 16 respondents) indicated that it’s a personal task, while 57% (nine out of 16 respondents) indicated that it was usually a work related task. These numbers contradict figures released in Morris’s (2008) survey in which 65% of the respondents reported the tasks as being personal rather than work-related. A possible reason behind this difference might be related to the difference in sample size as Morris’s (2008) online survey included a fairly large sample (around 204) employees in a technology company.

10 out of 25 VI respondents preferred email exchanges to communicate with their CIS partners rather than sitting together in the same place or through voice calls. 9 out of 23 sighted users preferred direct conversation either when sitting in the same place or over the phone as shown in Figure 4.2. We speculate that a possible reason behind the preference of VI users for email communication could be due to verbal communication clashing with output from their speech-

based screen reader. The cognitive load associated with the overlap of verbal communication and speech-based screen readers has been highlighted in a previous study (Chandrashekar et al., 2006). Therefore, given VI users' previous experience in collaborative web browsing and search activities, VI users might find communicating via email a means of overcoming these issues.

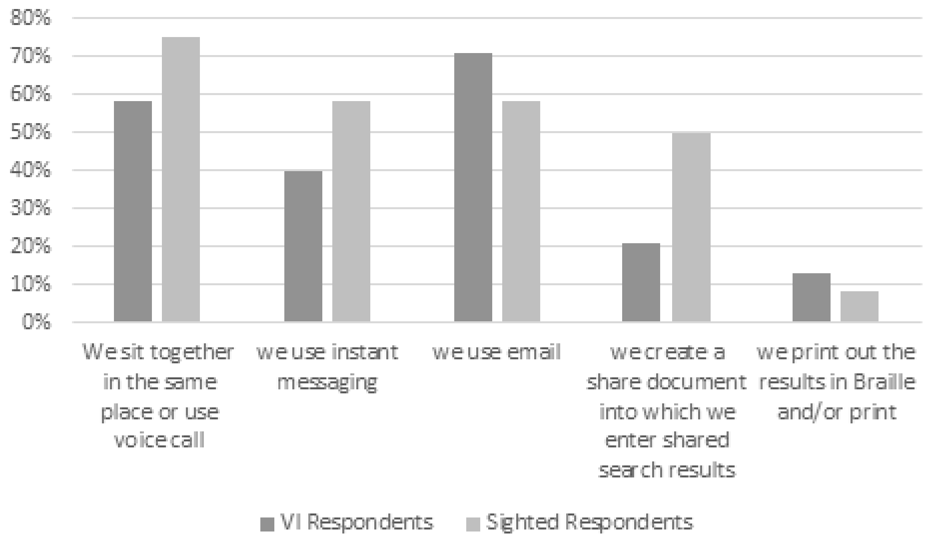

Figure 4.2 Methods used to communicate during CIS activities.

4.8 Limitations

The number of survey respondents may seem small; however there are two reasons for not considering a bigger sample. Firstly, the aim of this survey was to examine whether CCIS activity was feasible and to discover the extent to which it takes place within the population of experienced VI web users. In this sense the survey can be seen as a feasibility study for the work described in the rest of the thesis. We employed purposive sampling by sending the questionnaire to specific mailing lists as described in 4.3. Secondly, the data analysis employed in this study involves simple descriptive statistics, in which average values and percentages are used to present the responses. Therefore, a small sample size will suffice (Wilson and McLean, 2010, p. 165).

4.9 Chapter Summary

This chapter presents the findings of a survey that aimed to explore the current state and nature of CIS activity in both groups. The survey shows that both populations do regularly engage in CIS activities. The survey also shows that accessibility issues have an influence on the differences in CIS behaviour between VI and sighted users; for example the different preferences for the modality of communication during CIS activities. It is important to assert here that this survey was not intended to be comprehensive, but the intention was to obtain an idea of the extent of CIS activity in the two populations, and to begin to examine differences in CIS behaviour between them. The survey informs the work that follows, as previous work in this area provided mainly only anecdotal evidence that CIS activity occurred on a regular basis involving VI users.

Chapter 5 Study 1: CCIS between VI and Sighted Users

5.1 Introduction

Students or co-workers frequently complete assigned information retrieval tasks collaboratively, as detailed in the literature review (Large et al., 2002; Morris, 2008). Collaboration not only occurs in educational or professional environments, but also in social conditions such as friends planning a trip or family members purchasing a new home. As CIS happens in a variety of activities, studies have investigated the prevalence and frequency of users' involvement in such activities. Capra et al (2011) surveyed 452 people online in the United States and they reported that CIS occurred with the following frequencies; 7% daily, 29% weekly, 58% monthly and 4% never.

Morris (2013) revealed a higher percentage of use. In a sample of 167 United States based web users, 11% reported they perform CIS daily, and 38.5% reported performing it at least once a week. We asked similar questions in our preliminary survey in chapter 4. Before commencing this study, we also asked the participants in the pre-study questionnaire about the frequency with which they get involved in CIS activities. Table 5.1 is taken from the results of the pre-study questionnaire, and it shows participants' answers to the relevant question. Over 21% of study 1 participants stated that they do participate in CIS activity on a daily basis. 14% of both sighted and VI users stated that they participate in a CIS activity at least once a week.

	VI participant	**Sighted participant**
Daily	21%	0%
Once a Week	14%	14%
Once a month	36%	21%
Once in the Past Six Months	7%	43%
Never	21%	21%

Table 5.1 Frequency of CIS activity.

Previous research has focused on providing software solutions to either facilitate the process of CSCW or CIS. However these software tools assumed that all collaborators are able to interact with the system through the same modality (the visual modality). The focus on this modality does not address issues faced by users who access the system using different modalities such as haptic and/or audio. The purpose of the observational study reported in this chapter is to explore CCIS behaviour between VI and sighted users in co-located and distributed conditions. The overall aim of this study is to better understand the CCIS process, identify the challenges that occur, and to look into the effect of CCIS on the basic stages of information seeking.

5.2 Motivation and Contribution

The results of our preliminary survey revealed that 56% of VI respondents engaged in collaborative web searches with co-workers, friends and family. 46% of sighted respondents confirmed that they also engage in such an activity. Results of other surveys that involved larger samples showed a higher percentage of people who engage in a CIS activity (Morris, 2008; Capra et al., 2011; Morris, 2013).

This activity has not been reported in previous research, even though it may commonly occur between VI users and those who use different access modalities. The motivation behind this observational study is therefore to explore the nature of interactions between VI and sighted users during collaborative exploratory searches. This study will allow us to examine the challenges faced during CCIS, the pattern of behaviour that emerges during the interaction, and the effect of cross-modality on the stages of information seeking. This will enable us to begin to form an understanding of how CCIS can be performed and the issues relating to the various stages of the CCIS process.

We decided to focus on two main aspects of CIS in this observational study. The process of CIS, is rarely been examined in previous literature, and the majority of research done in this area has been application-specific (Smeaton et al., 2006; Morris and Horvitz, 2007a). We also aimed to examine the features of CIS in the presence of different modalities. The next section will introduce the research questions to be examined.

5.3 Research Questions

We aimed to identify and understand the challenges faced by VI and sighted users while performing a collaborative search and the techniques they use to aid the process. We looked into the effects of cross-modal interaction on the different aspects of CIS identified in the literature, which are division of labour, the provision of awareness information, the process of exploring results and the process of results management (Morris, 2008). The questions this study is looking to address can be divided into two different themes:

Theme 1: The Effects of the Presence of Cross-modality on Information Seeking Stages

There is still no clear definition of CIS, as discussed in section 2.4, and in order for us to study the collaboration that happens in stages of the information seeking, in this study we consider the Marchionini and White (2008) model of individual information seeking. In their model they introduced information seeking as a sequence of discreet processes. Looking at each stage separately can help us in identifying the effects of cross-modality on each stage. The aim is to answer the following questions:

RQ1: What stages of the information seeking process were done collaboratively and how?

Shah and González-Ibáñez (2010) studied how IS stages are typically completely individual. Nevertheless, collaborators may choose to work together at many stages of the process (Shah and Marchionini, 2010). Previous studies also stress that collaborative activities are generally ill structured (London, 1995). Hence very few efforts have been made to define a model of CIS activity (Wilson and Schraefel, 2009; Evan and Chi, 2008). This question aims to explore the amount of collaborative work that happens in each stage of CCIS, and that techniques employed by participants to enhance it. This question also aims to identify the stages in which collaboration most frequently occurs.

RQ2: Does the presence of different modalities affect the results exploration and search results managements stages?

RQ3: What are the strategies and techniques employed to manage search results?

Previous research on VI users' IS behaviour highlighted that most challenges are encountered during the results exploration phase (Sahib et al., 2012). Examining large amounts of search results using screen readers can be a frustrating process, as the sequential nature of speech imposes a number of issues on the VI web user (Stockman and Metatla, 2008; Murphy et al., 2007a). Therefore this question aims to identify the affect the presence of two modalities have on group performance, as well as techniques group members employed to aid the process. This question also explores the management of search results in the presence of a common goal between group members who use different access modalities. It seeks to identify approaches and techniques used to organize and manage search results.

Theme 2: The Effects of the Presence of Cross-modality on CIS Concepts and Features

This observational study aims to identify and understand the challenges faced by VI and sighted users while performing CCIS tasks, as well as the strategies and techniques used to overcome these challenges. Thus it looks into the effect of cross-modal interaction on the different aspects of CIS identified in the literature, particularly awareness and division of labour (Morris, 2008). We identified the following specific research questions:

RQ4: What mechanisms are used to facilitate awareness? And, relatedly.

RQ5: To what extent are participants aware of each other during the collaborative search task?

Literature on CSCW has always considered awareness as a fundamental aspect in interfaces that support collaboration. Providing an appropriate level of awareness can certainly enhance the CIS process (Shah and Marchionini, 2010). The present study examines strategies employed to utilize group awareness. It investigates the methods used, especially in the absence of common access modalities, where users can simply share the modality to be aware of one another's work.

RQ6: What strategies are employed regarding the division of labour? And.

RQ7: Is the labour divided equally between participants?

These questions examine division of labour strategies that emerge in the presence of two different modalities and the reasons behind employing these strategies. RQ6 also looks into the amount of work completed by each pair in the study and issues that influence the division of labour between partners.

5.4 Study Design

The observational study started by administering a pre-study questionnaire relating to demographic information about the participants. This was followed by a structured observational study that involved pairs of participants conducting two separate search tasks. One task was performed in a co-located condition, and the other task was performed in a distributed condition. In structured observational studies participants know that they are being observed while they are being asked to perform a certain task instructed by the observer (Wilson and MacLean, 2010). Each participant was interviewed after each task in order to examine the issues encountered while performing the tasks.

5.4.1 Participants

14 pairs of participants, each pair consisting of one sighted and one VI partner, took part in the study. They were contacted via mailing lists, as described in section 3.10, and they were financially compensated for participating at the rate of seven pounds per hour. Table 5.2 details participants' demographic data. When VI participants were asked about their use of assistive technology they all highlighted JAWS as being their primary screen reader. Their use of assistive technology is summarised below:

- Five participants use JAWS screen reader only.
- Three participants use both JAWS screen reader and Braille displays
- Two participants use JAWS and Voiceover, two participants use JAWS and Voiceover screen reader and Braille displays
- One participant uses JAWS, Voiceover and the NVDA screen readers as well as Braille displays
- One participant uses JAWS, Voiceover and system access.

	VI participants	Sighted participants
Age	2(21-29), 4 (30-39), 3(40-49), 5 (50-59)	2(18-20), 3(21-29), 3 (40-49), 5 (30-39), 1(50-59)
Gender	9 Male, 5 Female	8 Male, 6 Female
Qualification	2 Undergraduate, 10 Postgraduate, 2 GCSE	3 Undergraduate, 6 Postgraduate,5 GCSE
Browser used (multiple answers)	12 IE, 8 Safari, 5 Firefox	6 IE, 4 Firefox, 3 Safari,1Google Chrome
Search engine used (multiple answers)	14 Google, 1 Yahoo, 1 Bing	13 Google,1 Bing, 1 Yahoo
Frequency of CIS activity	3 Daily, 2 once a week, 5 once a month, 1 once in the past six months, 3 never	2 Weekly, 3 once a month, 6 once in the past six months, 3 never
Examples of latest CIS activity	3 Trip planning, 5 shopping online, 1 Searching music news and events, 2 Research papers publications.	3 Shopping, 2 gathering information for a work project, 5 trip planning, 1 Searching for YouTube videos
Sharing search results via smart phone	8 Yes, 6 No	10 Yes, 4 No
Application used to share search result through smart phone (multiple answers)	4 WhatsApp, 6 iMessage, 3 Text Message, 2 Facebook Messenger	2 Skype Messenger, 7 text Messages, 5 WhatsApp,4 message

Table 5.2 Demographic information about participants.

5.4.2 Set-Up

The intention of this study is to observe participants in real world environments; studies were therefore carried out in the VI participants' workplace. They were asked to use their own PCs and the web browser and search engines they normally use. In the distributed condition, participants were seated in different locations and were told that they were free to use any method of communication they preferred, for example email, instant messaging, shared documents, or any tool they found suitable. In the co-located condition, participants were seated in the same room and were asked to communicate verbally, though they were told they were free to use any additional communications tools they wished.

The sessions were all videotaped with the consent of the participants and both participants' screens were captured using screen recording software. The VI participants' screens were captured using a video camera, as we noticed in the pilot that screen recording software can slow down screen readers. Additionally we noted down observations during the sessions.

5.4.3 Task

A search task was constructed to allow the collaborators to perform an exploratory search. Section 3.6.1 describes the criteria for the design of the exploratory tasks. In the co-located condition, the participants were asked to work collaboratively to organize a business trip to the US and for the distributed task they were asked to plan a holiday to Australia. Each task involved visiting three cities; participants were required to arrange travel and accommodation in each city, and they were also given dates of engagements in these cities. The numbers of activities and engagements were designed to be equal in both tasks. Appendix B.3 includes details of all tasks used during the study.

5.4.4 Procedure

Before performing the tasks, participants were briefed about the purpose of the study and their given tasks. They were also given an information sheet to read and a consent form to sign. Each session included three main parts:

1. Participants were asked to complete a pre-study questionnaire. This questionnaire collected demographic data about the participants, in addition to getting information on the type of assistive technology they were using, their familiarity with search engines and how long they have been working together. The pre-study questionnaire can be found in Appendix B.2.

2. The pairs were then asked to start performing a CIS task, using the same search engine and assistive technology used in their daily work activities. The order of the tasks was counterbalanced across the pairs to minimize the influence that the order might have on the collected data. The users were stopped 35 minutes from starting the task.

3. A brief semi-structured interview was conducted with each pair when the task was completed. This brief interview helped in discussing the issues and challenges observed. It also allowed us to identify which parts the participants felt were hard. Participants were also asked about other challenges they face when they perform similar activities. Finally suggestions and possibilities to improve the CCIS tasks were discussed. The main questions asked can be found in Appendix B.4.

5.4.5 Data Collection

Participants' demographic information was captured through the pre-study questionnaire which contains a combination of close and open-ended questions. During the observational study the main source of data was the video recordings of the interaction between pairs and their screen recording.

All recordings were then transcribed and analysed to identify emerging patterns of behaviour, as described in Section 3.8.1.

Semi-structured interviews were conducted individually with each participant to complement the data collected during the study. The aim of conducting the interviews after the observational study was to allow us to discuss in detail the issues that arose during the interaction and to know the views of the participants about ways to enhance this sort of collaborative activity.

5.5 Results

In this section we present the results of the observational study. This section looks at different aspects of the activity. It provides a detailed description of different aspects of the process using a combination of qualitative and quantitative measures. When referring to a specific participant, or using direct quotation, we identify the participant using [VP, Sx] to refer to the VI participant and [SP, Sx] refers to the sighted participant; x indicates the ID number of the pair.

5.5.1 The Stages of the Process

From the verbal conversations in the co-located condition and chat and email logs in the distributed condition we identified a common pattern which the collaborative information seeking process comprised as described in section 3.8.1. In general the process starts with a stage in which the pair divides the tasks to be performed. In this stage, usually one of the participants takes the lead and assigns tasks to themselves and to their partner. During this process the other partner might either agree on the tasks s/he is being given or suggest an alternative task organisation. For instance, visually impaired experienced web users sometimes anticipated that certain tasks were likely to take longer to complete, therefore they sometimes suggested they performed other tasks, while their sighted partner undertook the task that was likely to contain accessibility problems. In the co-located condition an iterative process was observed. This process mainly involved three stages:

1. Stage 1: In the first stage the pair spent 2 to 5 minutes looking into and discussing the task. The discussion at this stage mainly related to an initial division of labour. At this stage the task was divided into smaller sub-tasks, and in the majority of cases partners only decided on the first sub-tasks. However they would have quite a good insight about the type of task they would be performing next. When dividing labour participants would agree on the type of task such as flight booking or activity arrangements, or the name of the city for which they were sorting out flights and activities. The approaches to dividing labour are further discussed in section 5.5.2.

2. Stage 2: After each partner was assigned a sub-task, each participant starts to perform the information seeking process individually.

3. Stage 3: Once a piece of information was found (e.g. a sub-task was completed), participants usually interrupted and notified their partner about the completion of this sub-task. Following this they discussed the outcome and search results. In the co-located sessions the discussion which we refer to as stage 3 always revolved around three main aspects: division of labour, making sense of the results and reviewing the remaining sub-tasks. Stages 2 and 3 would then be repeated until the task was completed.

In all distributed tasks a common pattern of behaviour was observed. After the initial division of labour both participants performed the information seeking tasks individually and shared the results via email or instant messaging. There was no evidence of the element of stage 3 discussion seen in the co-located sessions where participants would again discuss the division of labour. However it was observed that if one participant completed all the tasks assigned to him/her, they would decide to complete their partner's outstanding tasks. Additionally there was little activity that could be classified as making sense of the results.

5.5.2 Division of Labour

Division of labour is considered a central activity in the process of CIS. It is important for the participants to agree on the work being done and to avoid any duplication of effort. As mentioned above, the conditions (co-located or distributed), certainly influenced the division of labour and the way participants worked together to complete the task.

In the co-located condition it was observed that even though participants divided the labour, and each had their own sub-task they needed to perform, the pair continued to discuss them throughout the process of exploratory search. Morris (2008) referred to this approach as the ‘divide and conquer’ approach. This appeared in two stages of the CIS process in this condition; it appeared in the initial division of labour and again when users discussed and reviewed the outstanding tasks. The initial discussion usually concluded with a clear understanding of the way the task was to be divided. In 10 out of 14 pairs in the co-located condition the VI participant led the discussion about the division of labour and assigned the tasks to his/her partner. In four pairs the division of labour was led by the sighted participant.

As indicated in the task description the task required participants to plan a trip to three cities. The participants were required to collaboratively organize two or more activities and accommodation, as well as the travel arrangements between the three cities. Two approaches were observed in dividing the sub-tasks between partners:

1. According to the nature of the sub-tasks: assign one partner to perform searches related to bookings such as looking up the travel and accommodation details, and assign the other partner to perform searches related to organizing the activities.

2. According to the cities: divide the task so that each partner would complete the travel and accommodation bookings and organisation of activities within one city.

In terms of the ways collaborators divided the labour in the co-located condition 13 pairs of participants divided the sub-tasks according to the type of sub-tasks, while one pair of participants divided the sub-tasks according to the cities involved. In the 13 pairs who chose dividing the sub-tasks according to the type of sub-task, seven VI participants suggested that their sighted partners perform the flight and hotel bookings as they know that type of search can involve websites that may have inaccessible or difficult components, particularly inaccessible web forms. A VI participant (whose sighted partner was actually her personal assistant) commented *"I usually assigned travel bookings to my PA, as these websites can sometimes be hard to work with*" [VP, S6].

Unlike the co-located condition, participants in the distributed condition worked more independently and only notified each other when a task was completed. Morris referred to this strategy as the 'brute force' strategy. As in the co-located condition, usually one participant would lead the process of dividing the labour. In seven out of 14 pairs the VI participant led the division of labour and assigned the tasks to his/her partner. In six pairs the division of labour was led by the sighted participant, while in one pair both partners discussed and agreed on the distribution of labour equally.

Pairs divided the labour between them using one of the two approaches described earlier for the co-located condition. 12 pairs of participants divided the sub-tasks according to task type and two pairs of participants divided the tasks by cities. In the 12 pairs who used the task type approach, 10 VI users suggested that their sighted partners perform the flight and hotel bookings for accessibility reasons,

5.5.3 Task Completion

Task completion can be considered as a metric of performance. The participants were asked to stop after 35 minutes; only one pair from each condition was able to complete the task within 35 minutes. In the co-located condition the pair comprised a manager and her personal assistant; and in the distributed condition, the pair comprised a VI financial analyst and a sighted Computer Science PhD student who had never previously worked together. The average number of sub-tasks completed in the co-located condition was 9.29 (SD= 2.01) which was higher than the average number of sub-tasks completed in the distributed condition 8.57 (SD= 2.34). The differences were not significant at ($t(26) = 2.05$, $p= 0.59$). In both conditions sighted participants performed a slightly higher number of sub-tasks. However the difference was significant in the distributed condition ($t(13) =2.17$, $p= 0.004$). Data obtained from the observations and post-study interviews indicates the main reason why VI participants completed fewer sub-tasks in the distributed condition was the time required to switch between the three main applications being used: the internet browser, the email client or chat messaging application and the document processing application.

Percentage number	**Co-located condition**	**Distributed condition**
Sub-tasks completed by the sighted participant	40%	41%
Sub-task completed by the VI participant	32%	29%
Sub-tasks completed together	2%	1%
Uncompleted sub-tasks	26%	30%
Overlapped sub-tasks	2%	3%

Table 5.3 Summary of sub-tasks completed by participants in both conditions.

Table 5.3 shows the percentage number of sub-tasks completed, sub-tasks completed together, incomplete sub-tasks and sub-tasks that overlapped. Two factors were highlighted as the reason behind completing a task together. One of these reasons is related to needing to look at search results together, and to subsequently make sense of the retrieved information in collaboration. The other reason was that some websites were inaccessible and it was impossible for the VI partner to complete the task individually.

Figure 5.1 illustrates differences in teams' sub-tasks completion in both conditions; in all sessions the pairs in the co-located condition completed more tasks (except for pairs S12, S9, S7, and S3). In these four pairs the difference in their performances in both conditions was no more than 2 sub-tasks. The most apparent difference in pairs' performance was recorded in S4 and S6. They performed better in the co-located condition, and the difference between the two conditions was four sub-tasks for S4 and three sub-tasks for S3.

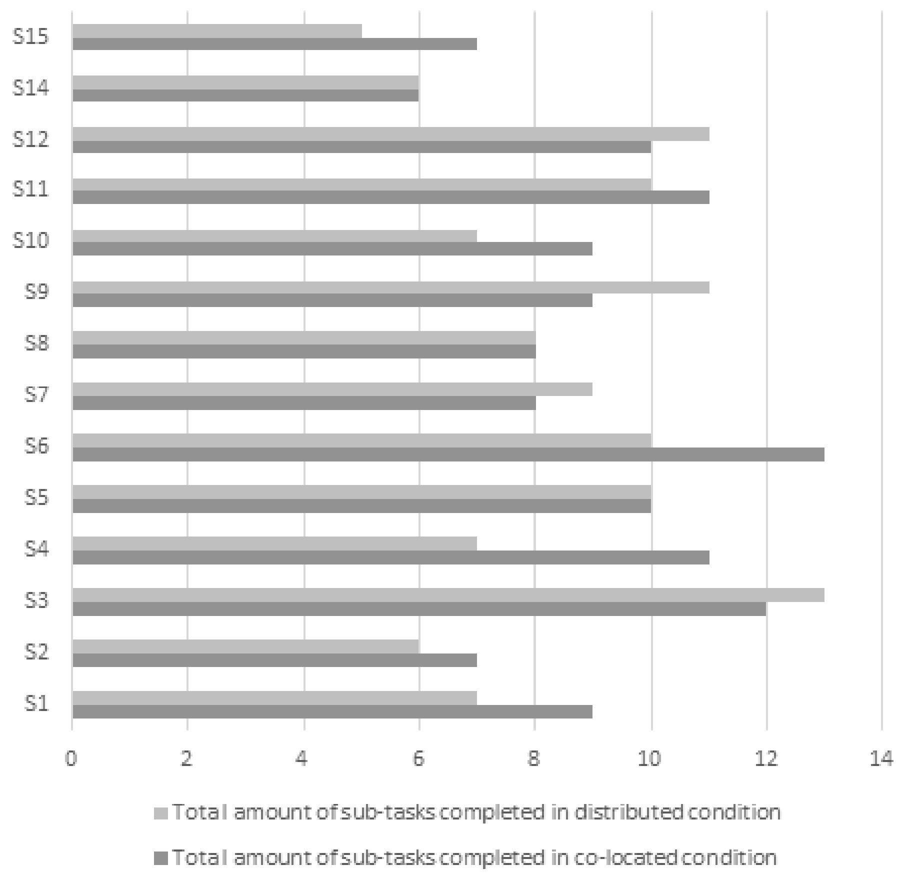

Figure 5.1 Differences in sum of the sub-tasks completed by each pair in both conditions.

5.5.4 Time Intervals

We recorded the time spent by participants on each stage of the IS process. This includes the following stages: time spent entering a query, times spent viewing search results pages, time spent browsing websites, and time spent managing information. In addition, time spent dealing with an error (a connection error, interface error or accessibility issue) and time spent switching from one application to another.

Table 5.4 below shows the average time interval spent in each stage in both conditions. From the figures it is clear that the greatest differences between the two VI and sighted users was in the results exploration, retrieved information management, communication stages and switching from one application to another. VI users spent longer time than their sighted partners on the results exploration stage in both conditions. Differences were not statistically significant with t-test results at ($t(13) = 2.05$, $p= 0.06$) in the distributed condition and ($t(13) = 1.95$, $P=0.72$) in the co-located condition, according to our observations the main reason why VI participants spent more time on this stage was the serial nature of screen reader speech made the process of going through search results longer.

VI users spent less time managing information in the word processing document. However the difference in time spent by VI and sighted users in managing and organizing retrieved information was not statistically significant using t-test ($t(13)=1.95$, $p= 0.724$) in the co-located condition and ($t(13) =2.05$, $p= 0.06$) in the distributed condition. Additionally it was observed that VI users spent considerably more time switching from one application to another with ($t(27)= 1.04$, $p=0.3$) in the co-located condition and ($t(27)=2.95$, $p=0.006$) in the distributed condition. The applications were web browser and word processor or note pad in the co-located condition, in addition to the email client or instant chat application in the case of the distributed condition.

In the post-study interviews eight VI participants highlighted the difficulties of having to switch between three different applications (web browser, email client and note taking tool) during the process. While in the co-located condition they mostly used only two applications, the web browser and the note taking tool, explaining that switching from one application to another can be "*a waste of time*" [VP, S6] and "*consumes more effort*" [VP, S5].

The average time consumed browsing web search results was significantly higher in the co-located condition with t-test results at (t(26)= 2.27, p= 0.03). In the distributed condition participants spent a considerable amount of time using the email client or instant chat messaging service to provide awareness information. The difference between VI and sighted users is not statistically significant at (t(13)= 0.06, p=0.06) in the co-located condition and (t(13) = 0.75, p=0.46) in the distributed condition. At this stage, participants varied in the amount of time spent browsing a website; while some spent a longer time browsing websites in detail, others spent a short amount of time and only stored the website URL and some keywords. The information kept by participants is discussed in detail in section 5.5.8.

	Co-located condition		**Distributed condition**	
	VI participant	**Sighted participant**	**VI participant**	**Sighted participant**
Entering query term	02:38 [01:12]	02:08 [01:59]	02:51 [02:01]	01.37 [00:58]
Exploring search results	03:58 [02:39]	02:11 [01:49]	03:17 [01:52]	02:07 [01:17]
Browsing websites	14:29 [08:48]	14:19 [08:47]	10:44 [06:47]	11:49 [06:08]
Managing information	02:50 [02:25]	05:57 [03:06]	01:59 [01:52]	02:50 [03:52]
Chat	00:00	00:00	06:56 [03:25]	08:36 [04:37]
Encountering errors	00:23 [00:43]	00:00	00:20 [00:28]	00:01 [00:02]
Switching from one application to another.	01:45 [00:19]	00:35 [00:31]	01:21 [00:34]	00:47 [00:27]

Table 5.4 Time spent in each stage in both conditions in minutes. (Average [SD]).

5.5.5 Participants' Team Performance Satisfaction Levels

After completing each task participants rated their satisfaction level concerning their performance and communication levels, on a scale where 10 was the most satisfying, with 1 being the least satisfying. The average satisfaction levels can be found in table 5.5. The responses showed that VI users were significantly more satisfied with their performance in the co-located condition with t-test results of ($t(27)= 2.96$, $p= 0.006$). They felt "*more in control while discussing the task verbally*" [VP, S6] and that "*there were far less delays when switching between two applications than three applications*" [VP, S5].

	Co-located condition		**Distributed condition**	
	VI participants	**Sighted participants**	**VI participants**	**Sighted Participants**
Performance	6.82 [1.74]	6.89 [1.75]	5.96 [2.63]	7.21 [2.39]
Communication	7.78 [1.57]	7.61 [2.17]	6.53 [2.56]	7 [2.71]

Table 5.5 Participants' performance and communication satisfaction levels. (Average [SD]).

Sighted users were more satisfied with their performance in the distributed condition. There were no significant reasons identified when discussing this. In the post-study interviews four sighted participants highlighted that in the co-located condition, it was hard to communicate with their VI partners as they always seemed to be busy listening to the screen reader. They express that at some points they were hesitant to communicate as they might distract their partner. In spite of this, sighted participants were more satisfied with the communication in the co-located condition. In fact both VI and sighted users felt significantly more satisfied with communication levels in the co-located condition with t-test results of ($t(27)= 2.46$, $P=0.02$). Given the lack of shared workplace and group awareness information, participants felt the need to know their partners' progress, as stated by one of the participants: "[it] *would be a great help to avoid duplication when communication is hard or when the other partner is busy*" [SP, S8].

5.5.6 Information Exchanged between Partners

In the co-located condition, collaborating partners exchanged group awareness information verbally. As soon as the pair started performing the given task they started to exchange information about the task and its status. In the distributed condition five out of 14 pairs preferred using email, while the other nine pairs chose to use instant messaging. They usually notified each other when they completed a sub-task and started another one; they also asked their partner about their status. In other words they both supplied and requested information. Unlike verbal communication in the distributed sessions, an email can contain two or more categories of the data coding mentioned in the "information exchange" coding scheme (section 3.8.1). Below we present excerpts from two conversations taken from each condition that show examples of information exchange between participants.

Co-located condition- Verbal communication:

Dialogue 1:

[VP,S1]: *"Ok, flight is booked"* (Category: supplied, subcategory: what I did)
[SP,S1]:"*Yup, Good".*

Dialogue 2:

[SP,S6]: *"What you are doing?"* (Category: requested, subcategory: what you are doing)
[VP, S6]: *"Looking for hotels in Seattle".*

Distributed condition- Email exchange:

[SP, S1]: *"I will book the tourism site for the last day."* (Category: supplied, subcategory: what I am doing)
[VP, S1]: *"Ok, I will book the Melbourne and gold coast hotels."* (Category: supplied, subcategory: what I am doing)

Distributed condition- Instant messaging dialogue:

[SP, S4]: *"Ok, got the flight to Melbourne"* (Category: supplied, subcategory: what I did) – *"now I'm checking for the one that brings us to the gold coast."* (Category: supplied, subcategory: what I am doing)
[VP, S4]: *"Good. I found a tuxedo rental"* (Category: supplied, subcategory: what I did). *"I will now look for something to do in Melbourne on our free day*." (Category: supplied, subcategory: what I am doing)

Table 5.6 below summarizes percentages of occurrences in the identified categories of coding. According to the identified categories, the highest proportion of information exchanged was related to the supplied awareness information, while the proportion of requested information is low in both conditions. The cases where participants supplied their partners with information about "what they are doing" or "what they just did" is the highest in both conditions.

Percentage Number	**Co-located condition**	**Distributed condition**
Division of labour	15%	12%
Reviewing outstanding tasks	5%	1%
Request for assistance with a web accessibility issue	7%	1%
Viewing large amounts of information with sighted participant's assistance	2%	0%
Supplied information	37%	70%
Requested information	13%	8%
Task related discussion	21%	8%

Table 5.6 Percentages of occurrences of each information exchange category.

The information related to division of labour is further categorised in two subcategories as shown in the coding. In the co-located condition 75% of the information exchanged in this category related to the initial division of tasks, which happened at the start of the session. This exchange of information involved participants reviewing the task and discussing the division of labour by assigning tasks to one another. 25% of the information exchanged in this category was related to "reviewing the outstanding task" category. Interestingly this subcategory was seldom observed in the distributed condition, which indicates that remote collaborators tend to divide the labour at the very beginning of the task and do not discuss the status of the task later.

In terms of information exchanged relating to the progress of the task (as shown in table 5.6), the percentage of information supplied was far higher in the distributed condition as the participants provided and obtained awareness information. Table 5.7 below shows the average number of instances of information exchanged. In all studies the average number of pieces of information supplied by sighted users is higher, though the difference is slightly bigger in the co-located condition. The amount of information requested by VI users was slightly higher than the average amount of information requested by their sighted partners in the distributed condition, while in the co-located condition the average amount of information requested by their sighted partners was higher. The amount of information supplied is always higher than the amount of information requested. The results show statistically significant differences between the amount of information supplied and requested with a Chi-square test value of ($\chi2$=84.8, p= 0.001) in the distributed condition and ($\chi2$=28.12, p= 0.001) in the co-located condition.

	Information supplied		**Information requested**	
	VI participant	**Sighted participant**	**VI participant**	**Sighted participant**
Co-located condition	3.43 [2.5]	3.29 [2.40]	1.07 [1.82]	1.28 [1.38]
Distributed condition	3.5 [3.08]	4.5 [3.48]	1.25 [2.89]	0.42 [0.75]

Table 5.7 Summary information supplied and requested. (Average [SD]).

The sub-categories of the supplied and requested information in Figure 5.2 for both conditions reveals that instances of supplied information occurrences were more frequent than instances of requested information. A large portion of the supplied messages belong to the sub- category "What I am doing" in the co-located condition, and there was a significant difference at ($\chi2$= 20.81, p= 0.001) in sub-categories. This was not the case in the distributed condition, and the results were not statistically significant with Chi-square test results of ($\chi2$ =2.098, p= 0.35). However the "what I am doing" category also has the highest number of occurrences.

As discussed the amount of requested information was considerably lower than the amount of supplied information in both conditions. In the co-located condition there are statistically significant differences in the subcategories of information requested ($\chi2$=24.58, p= 0.001). The largest proportion of the requested information is from the sub-category "what you are doing". In this sub-category participants are asking their partner about their current activity. In the distributed condition there is a statistically significant difference in the occurrence of each sub-categories of requested information at ($\chi2$= 16.28, p= 0.001) with all messages belonging to only two of four requested information sub-categories. These sub-categories are "what you are doing" and "did you complete".

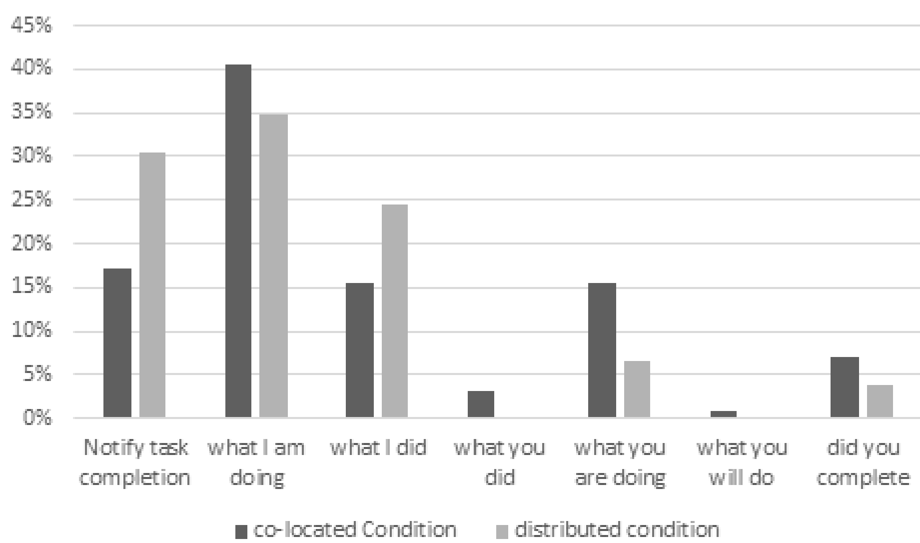

Figure 5.2 Percentages of the sub-categories of the supplied and requested information.

Concerning information exchanged relating to cross-modality in the co-located condition 85% of the cases relating to this category were accessibility issues. They either contained requests for assistance, or a notification that participants were facing an accessibility issue that may delay task completion. 15% of information exchanges in this category are related to viewing large amounts of information with the assistance of a sighted partner. This was not the case in the distributed condition, where only one accessibility issue was recorded, and no instances of requests for assistance to view large amounts of data were recorded. In the distributed condition it was observed that VI users would try an average of two websites when an accessibility issue was encountered in an attempt to solve the issue without asking their partner for help.

The most apparent difference in information exchanged between individual partners is that the amount of information exchanged between partners who were already familiar with each other was on average higher than the amount of information exchanged between partners who had not met before the study. In this study, four pairs were familiar with each other; S1 consisted of two university lecturers who were colleagues, S6 consisted of a manager and her personal assistant, S11 consisted of two friends and S10 consisted of a JAWS screen reader trainer and his son. It was observed that (S1, S6, S11) exchanged in total more information than the rest of the pairs in the study, as shown in figure 5.3. S10, on the other hand, exchanged less than the average amount of information exchanged by all pairs. There were no other notable differences in performance between pairs who were and who were not previously familiar with one another.

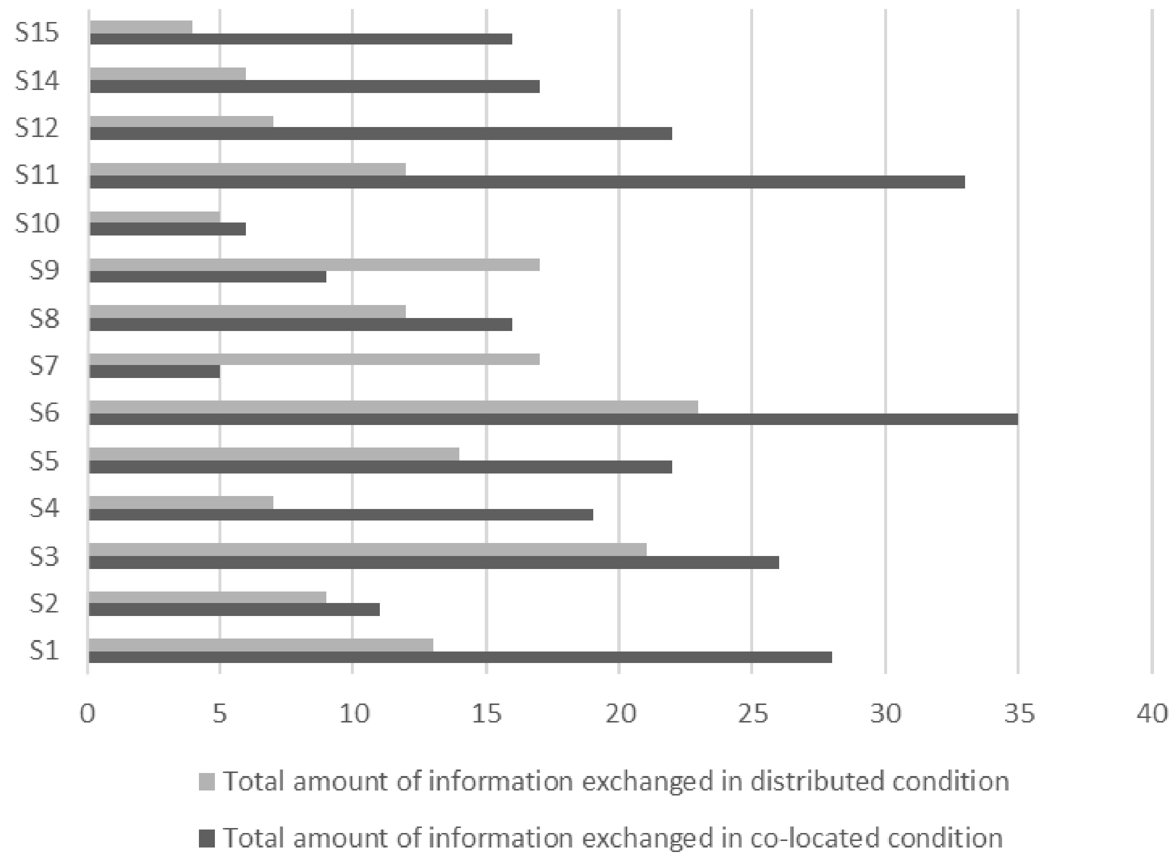

Figure 5.3 Total amount of information exchanged by each pair in both conditions.

5.5.7 Usage of the Received Information

When looking at the usage of the received information and what the receiver does with it, as shown in Table 5.8, the major difference between the two conditions was the amount of critical information exchanged. The amount of critical information was extremely low in the distributed condition in comparison with the co-located condition, which is related to the strategy collaborators used to divide labour. As described previously in the distributed condition the task is divided in a way that the sub-tasks are less dependent on each other; hence less critical information is exchanged. The amount of information provided to avoid duplication was slightly higher in the distributed condition. Collaborators tended to update each other more often when working remotely.

To investigate the relation between the purpose of information exchanged, the pair's performance and condition. We looked into pairs who performed well and pairs who performed poorly in both conditions. Figure 5.4 shows the percentage average numbers of information items exchanged by category in pairs with the highest performance and pairs with the lowest performance from each condition. The performance of each pair is measured by the number of sub-tasks completed in the session. The criteria used to rank the participants task performance is as follows:

1. The amount of the overall task completed.

2. The way the task is divided. Participants' task performance would be good if collaborators divided the task equally. In other words, each participant looked for the same number of pieces of information in the task or nearly the same (i.e. one sub-task difference).

3. The amount of task overlap; participants with good task performance usually avoided any duplication of effort.

We combined these three different criteria to come up with the overall ranking by firstly looking into the top three pairs in terms of the number of sub-tasks completed. We then looked into the differences and excluded any pairs where the difference in the number of sub-tasks completed was more than 1 and changed their ranking to the next down in line. Then we looked into the amount of sub-tasks mistakenly overlapped. In all of the top four pairs there were no occurrences of overlapping sub-tasks, hence the third condition was satisfied.

The criteria for choosing the worst performing pairs included:

1. The team who completed the smallest number of sub-tasks.

2. Where the team divided the task poorly between them, in which one participant would complete far more sub-tasks than the other participant.

3. Where a sub-task might mistakenly be completed by both pairs.

We combined these three different criteria to come up with the overall ranking by looking into the three poorest performing pairs in terms of the number of sub-tasks completed. We then looked into ways the sub-tasks were divided and excluded any pair where the pair performed equally, as the intention is to look at pairs who did not divide the work equally and completed the smallest number of tasks. The final criterion looked at the number of sub-tasks mistakenly done by both participants as this can be an indication of a lack of coordination between pairs.

	A	**B**	**C**	**D**
Co-located condition	19%	32%	17%	32%
Distributed condition	19%	43%	4%	34%

Table 5.8 Percentages of each category in the usage of received information.

When examining the sessions where partners performed very well in the co-located condition and sessions where partners performed badly in the co-located condition, we found statistical differences among the different categories ($\chi 2$= 10.48, p= 0.014). In the top three sessions, the average numbers of information exchanges related to information that was needed but not critical (category B) and filed away (category A) are high. In these top performing pairs, the average number of critical information exchanges (category C) was at the lowest, as was the number to avoid duplication of effort. Additionally, in the three worst performing pairs, as shown in figure 5.4 the amount of critical information exchanged (category C) was joint highest with (category B); while (category A) did not occur at all.

There were no statistically significant differences between pairs who performed well and pairs who performed poorly in the distributed condition ($\chi 2$= 5.65, p=0.13). However there were notable differences between the two groups. When looking into the studies where partners' performance is relatively low in the distributed condition, the amount of information exchanged to avoid duplication (category D) is slightly lower than the percentage when participants performed well. The occurrence of this category is high in comparison to other categories. The sum of the percentage categories A and B is higher in the best performing pairs. As observed in the co-located condition, category A did not appear at all in the sessions where pairs performed poorly.

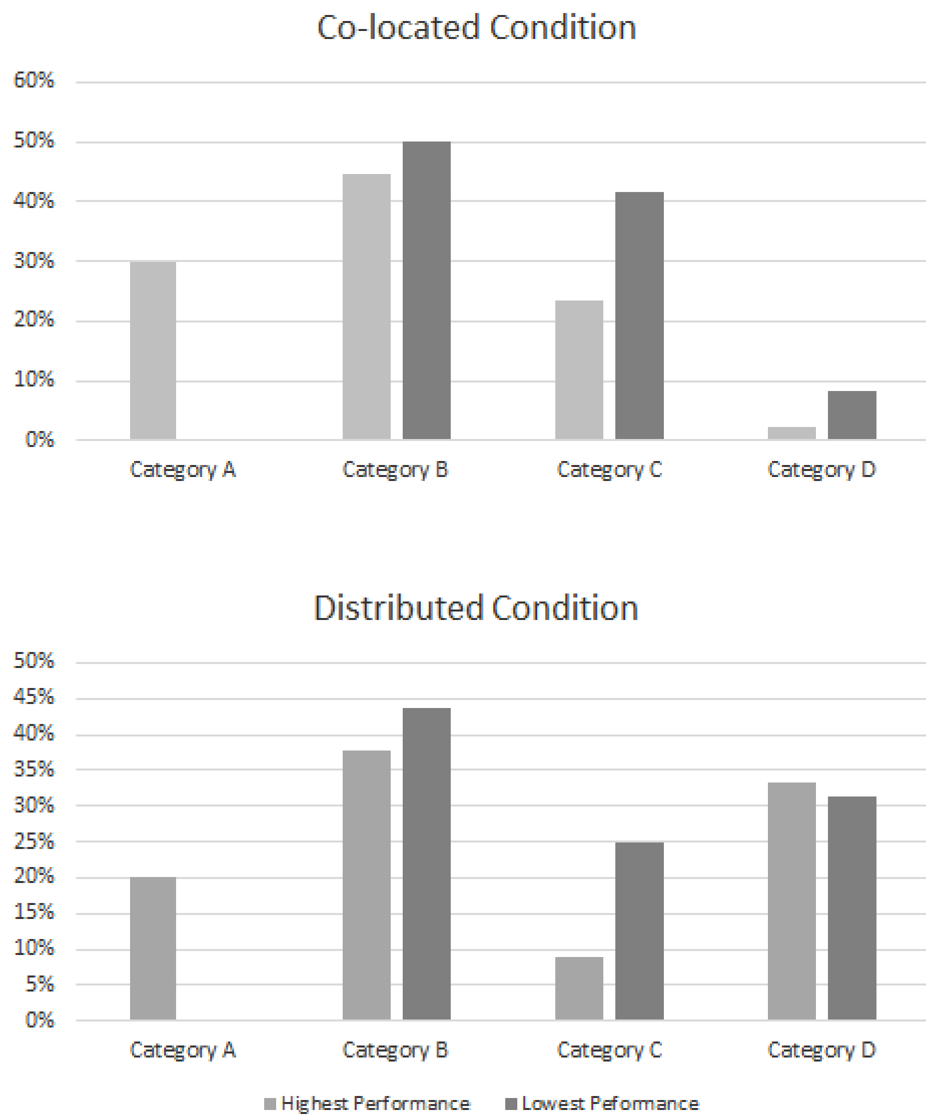

Figure 5.4 Percentage of each category in the sessions with highest and lowest performance.

5.5.8 Stages of the Information Seeking Process

For the most part the separate stages of the information seeking process were performed individually. Nevertheless in the co-located condition a number of instances were recorded in which the query formation, results exploration, query reformulation and the search result management stages were accomplished collaboratively.

Query formation: When assigned a task, participants immediately opened a search engine and entered a query keyword. With sighted participants the initial query would initially be broad, and once a relevant result set was found, the participant might choose to narrow down the search to a more specific query with more keywords to obtain the information they were seeking. The average length of the initial query entered by sighted participants was 2.65 words (SD= 0.84) in the co-located condition and 2.93 words (SD= 0.54) in the distributed condition. However the query formulation behaviour of VI users was somewhat different. The average length of the initial query entered by VI participants was 3.37 words (SD= 0.96) in the co-located condition and 3.31 words (SD= 0.95) in the distributed condition. In both conditions, the average length of queries by sighted participants was shorter than that of VI users. The result was statistically significant in the co-located condition at ($t(26)=2.11$, $p=0.045$) but not statistically significant in the distributed condition at ($t(26)= 1.28$, $p= 0.21$). The results agree with the findings of Sahib et al (2012) in the context of single user IS, that VI searchers tended to enter longer queries than sighted users, the explanation being that they felt more specific searches were more likely to reduce the volume of results they would need to browse.

Participants sometimes suggested query keywords for his/her partner. In all co-located experiments the average of 0.36 instances (SD = 0.66) of suggesting query terms was recorded, while only one case was recorded in the distributed condition. In situations where the participant was unable to find results that satisfied the information need, his/her partner usually suggested another query keyword. This suggestion was either based on prior knowledge, or based on the context of the task. For instance in the conversation extract below, one participant was finding a hotel in Los Angeles (L.A). This participant suggested the query keyword for her partner, who was looking for a restaurant to dine in L.A. She suggested that the restaurant had to be near the hotel, as shown in the excerpt below in the co-located condition:

[S6, SP]: *"I will look for a place to dine in L.A; you can Google restaurants near Beverly Hills".*

Search Result Exploration: The number of search results explored by sighted users (average 7.14, SD= 3.37) is significantly higher than VI participants (average 3.92, SD=2.12) with (t(26)= 2.79, p=0.0097) in the co-located condition for all experiments. Although the difference was smaller in the distributed condition, it was still statistically significant at (t(26)= 2.32, p= 0.02). The average number of search results explored by sighted users was 6.79 (SD= 2.38) and by VI users it was 4.71 (SD=2.64). Collaboratively exploring search results was only commonly observed in the co-located condition. In all conducted experiments an average of 3.75 instances (SD= 1.25) of exploring results collaboratively was recorded. The average number of search results viewed collaboratively is 0.5 (SD= 1.38). Collaboratively obtained results were triggered by the VI partner needing to explore more results faster. Examples of comments taken from two different sessions in which the VI partner asked the sighted partner to assist when exploring the search results are shown below:

Example 1

[S6, VP]: *"Could you just glance at these results yourself?!"*

Example 2:

[S8, VP]: *"It is listing a number of places, Can you see L.A. there?"*

Query Reformulation: This stage occurs when the user is not satisfied with the initial retrieved set of results and chooses to submit a new query. The new query might be a term from prior knowledge or from recently found information. Most of the time this stage was done individually with an average of 1.07 times (SD=1.14) in the co-located condition and an average of 0.7 times (SD= 1.24) in the distributed condition by VI participants. Reformulation of queries by sighted participants had an average of 2.93 (SD= 2.47) in the co-located condition and an average of 1.29 (SD= 1.98) in the distributed condition. This stage was collaboratively performed in only 3 instances in the co-located condition. In these instances the partner interrupts and suggests a query term when one partner is not satisfied with the set of results. An excerpt of a conversation that captures collaboratively accomplished query reformulation is shown below:

[S1, SP]: "*I think, perhaps Virgin Atlantic doesn't have direct flights to Las Vegas".*
[S1, VP]: *"Yes, this is what I was thinking about".*
[S1, SP]: *"Let us try another keyword; perhaps you can Google direct flights to Las Vegas".*

Managing Search Results: Since the task was conducted in one session, users did not employ favourites or bookmarks to keep track of required information. Participants tended to open multiple windows or tabs to keep track of retrieved information. Sighted users tended to open multiple tabs within a browser window whereas VI users tended to open multiple windows. When a sub-task was completed, VI users generally notified their sighted partners to write down and keep a note of the results.

In the co-located condition the most used tool was Microsoft Word; ten VI participants and seven sighted participants used it. The next most used tool by sighted participants was pen and paper; four sighted participants used a pen and paper to note down retrieved information. Additionally two VI participants and one sighted user employed the Microsoft Notepad application and one participant established Skype communication with their partner and added the retrieved information into the Skype session. In most of the conducted sessions, both participants would store the retrieved information in one of the previously mentioned forms. However in three sessions, only one participant noted down the retrieved information and the other participants entirely depended on their partner. In two sessions the sighted users kept track of the retrieved information and stored it, while in one session the VI user organized and stored the retrieved information in a Word file.

In the distributed condition, the most used tool was Microsoft Word with nine VI and five sighted participants using it. Three sighted participants requested a pen and paper to take notes, and two VI participants used the Microsoft Notepad application. In the distributed condition three VI participants and four sighted participants preferred storing their notes and retrieved information using the communication tool, which was either email or chat messaging.

It was observed that the content of the information noted down or exchanged by participants was of five types which included: a website link, a website link with details, details about the sub-task, simple keywords that refer to the information or copying a part of the webpage. Figure 5.5 shows the percentage of each identified category in the co-located and the distributed condition. The majority of information kept by both sighted and VI users in both conditions were either website links with details (52% in the co-located condition and 59% in the distributed condition) or details only (25% in the co-located condition and 16% in the distributed condition). There were no significant differences in terms of the proportions of information kept and exchanged by sighted and VI participants at ($\chi 2$= 3.13, p=0.53) in the co-located condition and ($\chi 2$= is 7.29, p=0.12) in the distributed condition. Additionally there was no significant difference between the amount of information kept and exchanged in both conditions ($\chi 2$= 4.67, p= 0.32).

There were no significant differences in the proportion of information kept and exchange between the two conditions. The amount of information kept by both VI and sighted users is nearly half the amount of information kept by sighted users alone. In fact in the distributed condition, sighted users exchange rate of information to VI users was 2:1. In the post-study interviews seven VI participants highlighted the difficulties of having to switch between three different applications (the web browser, the email client and the note taking tool) during the process. In the co-located condition the retrieved information was noted down but was not exchanged between the participants by any means. Participants were merely notifying their partners about their activities or asking their partner about theirs as a means of making themselves aware of their partner's progress. In the distributed condition, pairs shared the retrieved information via the communication tool.

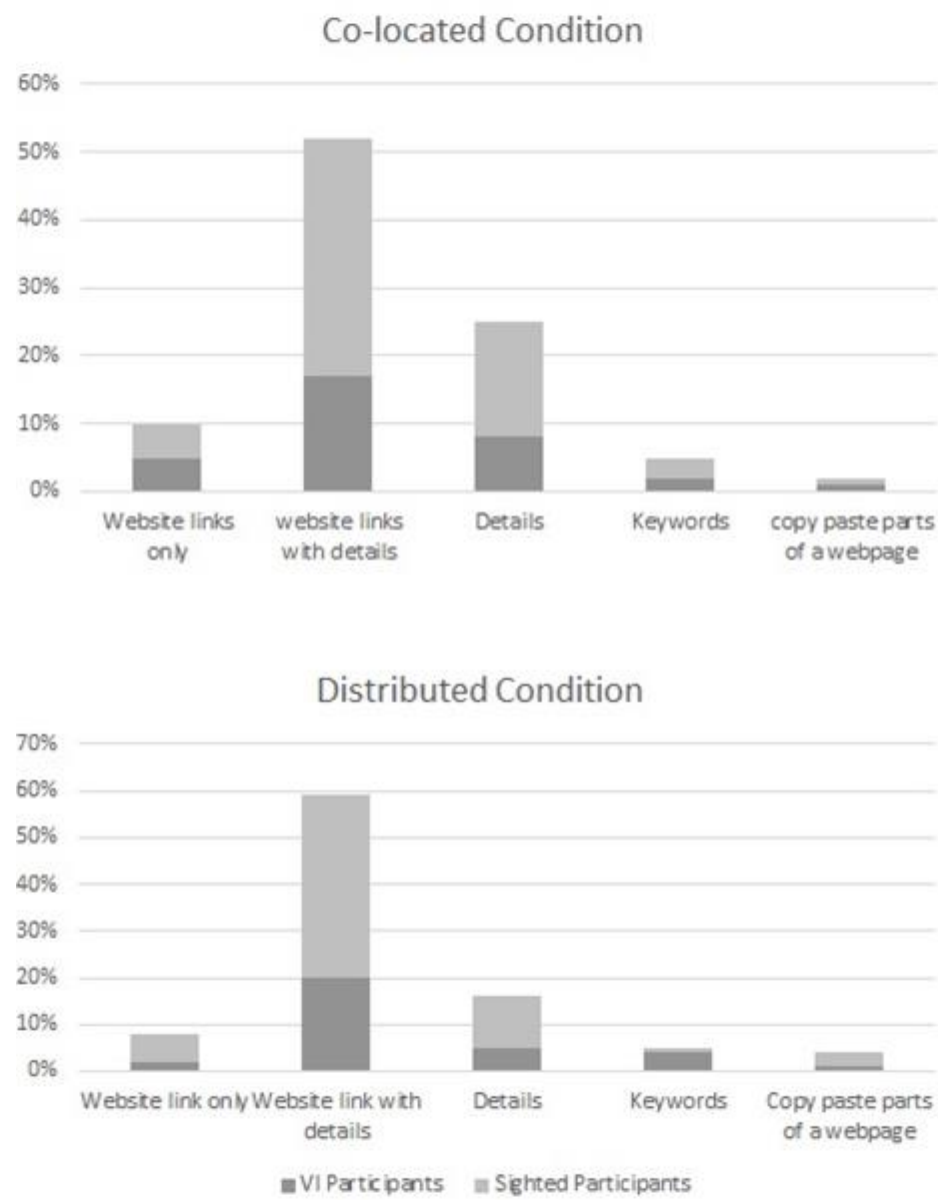

Figure 5.5 Percentage occurrence of each type of information kept or exchanged.

Structuring Search Results: The majority of VI and sighted participants stored the information in lists, without order or structure. However some participants organized the stored information in a relatively structured way by creating subheadings and adding the information related to the corresponding subheadings. In total, seven participants (four VI and three sighted participants) employed this kind of structure. Five of these seven participants (three VI and two sighted participants) employed this kind of structure in both the co-located condition and the distributed condition. The other two participants, one VI participant and one sighted participant, only employed this kind of structure in the co-located condition.

5.5.9 Challenges in Relation to Accessibility

The presence of two modalities impacted the way participants interacted during the task, and it influenced the division of labour in each condition. In the co-located condition it encouraged VI participants to ask for assistance from their sighted partners, whilst this was not the case in the distributed condition. In the co-located condition VI users thought it might be quicker if they asked for assistance from their sighted partner. VI participants asked for assistance from their sighted partner a total of 17 times; 13 times when they were encountering an accessibility issue and four times related to viewing large amounts of information with their sighted partners' assistance. However when VI users encountered an accessibility issue in the distributed condition they tended to keep trying to complete the task, trying an average of three websites before asking their sighted partners to assist them. The VI participants encountered a total of 14 accessibility issues in the distributed condition.

In the co-located condition, VI users thought it might be quicker if they asked for assistance from their sighted partners; 10 issues related to inaccessible websites occured. The majority of accessibility issues occurred while accessing hotel and flight booking websites which included components with accessibility problems. One participant described it by saying "*It is a very very very frustrating process*" [VP, S7]. Another participant commented during the experiment that "*most of the websites don't work with screen readers. I went to three websites and all of them don't work with JAWS because of accessibility issues*" [VP, S8]. In the interviews most of the VI users expressed frustration during interaction with websites that contained rich internet components such as Java Script, Flash videos, dynamic content and accessing embedded calendar objects. However two VI participants [VP, S6, and S2] stated that with experience they learned that there is usually a way around these issues but they preferred to request the assistance of their partner for the sake of saving time and effort to complete more tasks.

Three calls for assistance were not related to accessibility. Two issues related to the fact that the browser stopped working and the VI participant had to restart it. A third issue related to internet connectivity; for this issue the VI participant requested the assistance of the observer to look into the issue.

The majority of VI users employed heading to heading navigation when viewing large amounts of information with a sighted partner's assistance, three VI participants [VP, S1, S4 and S6] requested the assistance of their sighted partners to view a large number of search results. Both S1 and S6 were co-workers. One participant [VP, S4] referred to the experience as a "*struggle*." He added; "*unless I am familiar with the website, I will have to go through the whole website to understand the logic behind its structure*". When prompted about these incidents in the post-study interviews they stressed it was a quicker way to gain insight into the information and hence complete the given task.

In the distributed condition VI users did not ask for assistance from their sighted partners. A total of 14 issues occurred where VI users attempted to solve the issues by themselves. Ten accessibility-related issues were encountered which involved viewing websites that contained components which the screen readers were unable to render. Those components were mainly plug-ins with accessibility problems such as Flash, and Active X. When VI users encountered an accessibility issue in the distributed condition, they tended to keep trying to complete the task, and they did this by trying alternative websites. It was observed that a participant would try an average of three websites before involving their sighted partner to assist them. Aside from issues with web accessibility, three issues relating to reaching a text box in Skype were also recorded. In the distributed condition where participants used Skype messenger to communicate with their partner, two participants had issues in reaching the text box to send the message. One participant encountered the issue twice and the other participant encountered the issue only one time. The participants usually found a way of navigating to the text box without requesting assistance from the observer. One issue was attributed to the fact that the JAWS screen reader stopped responding, in which case the participant simply restarted the application.

Time spent resolving accessibility issues was not included in the overall total of time spent performing tasks. When an accessibility issue occurred and a VI participant requested assistance either from their partner or the observer, the timer was stopped and the sighted partner would be asked to stop the task. When the issue was resolved the observer turned on the timer and asked both participants to continue the task. The average time spent solving an accessibility issue in the co-located sessions was 23 seconds (SD= 0:43) seconds and 20 seconds (SD= 0:28) in the distributed sessions. The only requests for assistance for which the timer was not stopped was when VI participants asked for the support of their partner to navigate and look for required information, as it was considered a part of the CCIS process and not an issue that was stopping the process.

5.6 Discussion and Analysis

This section organises the presentation of the discussion of the results according to the two themes that categorise the identified research questions. The first theme discusses the process of IS; thus section 5.6.1 discusses the overall CIS process and the effects of the presence of CCIS on the process of IS. This part aims to address RQ1 to RQ3. The second theme looks into the different aspects of CIS, and so section 5.6.2 addresses research questions RQ4 to RQ7.

5.6.1 The Effects of the Presence of Cross-modal Collaboration on the Stages of IS

5.6.1.1 The CIS Process

Despite extensive research in this field in the past few years, there is no consensus over a single model or framework that describes the CIS process, although there have been a number of research attempts to develop models either to describe the CIS environment (Shah, 2009) or to classify the systems supporting it (Golovchinsky et al., 2009). Defining a framework for the stages of CIS is not within the scope of this study; however having an insight into the stages of the CIS process would be of benefit as it can help identifying the phases influenced by the presence of two different modalities.

There is evidence of similarities in the general stages of the process between individual and collaborative behaviours in information seeking. Hyldegard (2009) and Shah and González-Ibáñez, 2010) examined the applicability of Kuhlthau's (1991) process of individual IS in the context of a group. The results of the two studies were similar, and both concluded that although the stages of Kuhlthau's process had parallels, the additional social dimension of CIS needed to be addressed. The findings reported in our study show that there is clear evidence of similarities between the stages of the individual IS process and stages of collaborative IS. In general stages were performed individually; however collaborative behaviour occurred in almost all stages. The frequency of occurrences between stages largely differed; collaboration occurred mostly in the search results exploration stage in the co-located session and in the results management stages in both conditions.

In terms of the overall process it would always start with a discussion about the task and an initial division of labour. London (1995) described these stages as the 'problem condition phase' and the 'direction condition phase'. In these initial stages collaborators spend time understanding the problem, identifying resources required for solving it, organizing group activities and agreeing the division of labour. London (1995) explained that collaborators then complete the task[s] assigned to them and notify their team members when these tasks have been completed. A similar process structure emerged in the experiments we conducted, as the pairs started by discussing and making sense of the given task. They then assigned different tasks to each other and started conducting the IS task individually. However differences were quite apparent in the way pairs collaborated in each condition. Collaborators tended to work more independently in the distributed condition and only notified each other when a task was completed. As seen in the results section, it was observed that in cases when the VI partner delegated tasks that might contain inaccessible interactions to their sighted partner, this action was likely to enhance the efficiency of the pair in completing the task, as it meant the VI user was unlikely to encounter an accessibility issue.

5.6.1.2 Collaboration in the Stages of IS

This section addresses RQ1 and RQ2. In order to address RQ1 we investigated the stages of IS by identifying the collaboratively completed stages, the way the stages were conducted and the reasons that triggered the collaboration. On the other hand RQ2 looks at the differences when performing the stages of results exploration and results management in two modalities. This section starts by addressing RQ1, followed by RQ2.

RQ1: What stages of the IS process were done collaboratively and how?

As described in results section 5.5.8 most of the CIS stages were conducted individually apart from the results exploration and results management stages.

Results Exploration: Collaboration was triggered when VI participants viewed large amounts of information with their sighted partner's assistance, or by both partners deciding to explore search results together. The average number of search results viewed collaboratively was higher than the average number of search results viewed by VI participants alone. Screen readers' presentation of large volumes of data imposes a number of challenges such as short-term memory overload and lack of contextual information or a holistic view of the data presented (Murphy et al., 2007a; Stockman and Metatla, 2008). In fact the results exploration phase is highlighted as one of the most challenging stages faced by VI users during the IS process (Sahib et al., 2012). Additionally currently used screen readers provide almost no mechanism for displaying an overview of search results.

Results Management: Although participants were not explicitly asked to create a common outcome the results management stage was actually completed collaboratively in three sessions as described in section 5.5.8.

RQ2: Does the presence of different modalities affect the results exploration and search results managements stages?

Result Exploration: The presence of different modalities has an effect on the number of results explored. The number of results explored by VI participants was significantly lower than the number of results explored by their sighted partners. This is due to the linear nature of speech. This finding is in agreement with Ivory et al. (2004) and Sahib et al. (2012).

Result Management: The observations showed that the amount of information kept and noted down by sighted participants was higher than the amount of information noted by VI participants. Similarly, when looking at information exchanged, the amount of information provided by sighted users was double the amount of search results information provided by their VI partners. Reasons for this are twofold. The first is that sighted users viewed more results than their VI partners. The second reason is related to the cognitive overhead that VI users experience when switching between the web browser and an external application used to take notes. This is likely to increase the cognitive load of VI users and hence slow down the process. The effect of this is more apparent in the distributed condition where VI users are required to switch between three applications: the email client or instant chat application, the web browser and the note taking application. Therefore more VI participants preferred their sighted partners to take notes of the results retrieved in the distributed condition. Delegating this task to the sighted partner is a way to reduce the cognitive load imposed by the search process (Chandrashekar et al., 2006).

RQ3: What are the strategies and techniques employed to manage search results?

With the lack of a shared workspace participants stored information individually, except for three sessions in which one participant was in charge of collecting and organizing the retrieved information. The retrieved information is stored in five forms as described in section 5.5.8. The most popular form was the website link and details associated with it. In terms of organization of the final outcome, most of the pairs stored them in the form of a flat list. However we observed individuals (four VI participants and three sighted participants) who employed a more structured approach, in which they employed headings for main activity, sub-tasks categories or city names within which headings the participant would organize the retrieved information. This approach can help the participant to re-find the information they have stored. However since this study only consisted of tasks of one session duration, participants generally did not use this approach.

5.6.2 The Effects of the Presence of Cross-modality on the Concepts of CIS

5.6.2.1 Awareness

Shah and Marchionini (2010) assert that in CIS activities the level of group and workplace awareness can play a significant role in the overall performance of the collaborators, and that supporting a sufficient level of awareness can have more impact on the time efficiency than any other feature of the CIS system.

RQ4: What mechanisms were used to facilitate awareness?

To answer this question, we investigated the content of information exchange between participants. In the co-located condition, the main method to implement awareness was verbal communication. However in many instances sighted partners were observed looking at the screen of their VI partner to be able to know their partner's status. In the distributed condition the only method to implement awareness was through email, Skype or instant messaging. To facilitate awareness of partner's activities while performing the task participants supplied their partner with information about the activity they were performing. The information provided can be classified into three types: information about the sub-task that has just been started, the sub-task currently being performed, and the sub-task that has just been completed at a given time. The information received can be classified into four forms; information not needed for the current sub-task, information needed but not critical to the current sub-task, information critical to the current sub-task and information to avoid duplication of effort.

The percentage of information provided by the participants was higher than the information requested. The amount of information supplied but considered not relevant for the current sub-task or considered not critical by the receiver of this information was relatively high in both conditions. Even though the sub-tasks are quite structured and the majority of the sub-tasks are not dependent on each other, participants constantly kept supplying each other with information to enrich group awareness in the absence of a tool that supported awareness in both conditions. In fact in pairs with a higher performance in the co-located condition, more than 60% of the awareness information exchanged was information that is not critical but might be used later (categories A and B).

When more information to avoid duplication was available, performance was higher in the distributed condition. This indicates that making this type of information available between distributed collaborators might enhance their ability to complete tasks in a timely manner. This was not the case in the studies performed in the co-located condition, as the studies with lowest and highest performance reported the same amount of information exchanged relating to duplication of effort. This indicates that facilitating the appropriate type and amount of awareness information is crucial to team performance and can increase team productivity (Shah and Marchionini, 2010; Shah, 2012).

RQ5: How often were participants aware of each other during the collaborative search task?

Participants tended to provide awareness information about their activities throughout the task. Two types of behaviour were observed to facilitate group awareness. The first was the awareness of a partner's activity at a given time. Participants needed to know their partners' actions at a certain point in time. In this example the participant either notifies his/her partner about the task they are working on or asks his/her partner about the task being performed. The second type is awareness of the overall progress on the task. This type of behaviour, which supports group awareness, usually happens when participants discuss their work. At discussion stages and mainly toward the end of the task participants frequently review the completed sub-tasks and identify the remaining ones. This type of behaviour was only apparent in the co-located condition.

Communicating awareness of the overall progress on the task was observed on average two to three times during the co-located sessions and was typically included within the division of labour discussions. This type of awareness information was not observed in the distributed sessions. The frequency with which it occurred is highly dependent on the number of sub-tasks accomplished and the division of labour strategy applied. In this type of behaviour one or both pairs tried to put together all the information found and then check for missing information.

5.6.2.2 Division of Labour

RQ6: What strategies were employed regarding the division of labour?

In the co-located condition pairs tended to employ the 'divide and conquer' strategy (Morris, 2008) to divide labour. Although the main task is divided into sub-tasks and assigned to each partner, the pair continue discussing the work together throughout the process. Whereas in the distributed condition, it was observed that the collaborators used a 'brute force' strategy. (Morris, 2008), in which the participants worked independently and only notified each other when a sub-task was completed. The observations from this study are in agreement with a study by Shah and González-Ibáñez (2010) that reported that collaborators tend to work more independently in a distributed condition.

In the co-located condition discussion about the division of labour occurred at two levels. Firstly in the initial discussion and then as a result of one participant interrupting his/her partner in order to complete their current sub-task together. In the co-located condition, the pair worked together at many points throughout the process. Three reasons were identified for these collaborations:

1. When the VI user was viewing large amounts of information with assistance from their sighted partner.

2. When browsing websites with inaccessible components, VI users asked sighted participants to perform the task or assist them in performing it.

3. The third reason is related to the context of the task. Participants tended to work together when choosing places to visit and discussing available choices. In this type of task participants worked together when exploring search results. Morris (2008) also highlighted this type of model where the type of task influenced the division of labour process.

In contrast in the distributed condition the discussion about the division of labour occurred only at the beginning of the task. Pairs divided the work and started work independently. Therefore critical information exchanges were at the lowest in the distributed condition, being 4% of the total information exchanged, while it was about 17% in the co-located studies. Additionally requests for assistance were lower in this condition. Similarly to the co-located condition, sighted users assisted VI users for the same reasons as 1 and 2 above, though VI partners seemed to be more reluctant to ask for this support in the distributed condition. As discussed in section 5.5.9 when a VI participant encountered an accessibility issue, they would try 3 websites on average before asking their sighted partner to assist them.

RQ7: Was the labour divided equally between participants?

As discussed in section 5.5.2 participants had two approaches when dividing labour. The majority (13 pairs in the co-located and 12 pairs in the distributed setting) divided the labour so that sighted participants performed the booking-related activity and the VI participants performed the event organization activity. VI participants emphasised that they chose this approach to avoid any issues related to accessibility. Vigo and Harper (2013) categorized this type of behaviour as “emotional coping”, in which users’ past experience relating to an inaccessible action that happened in the past in a similar webpage or similar task affects their judgment on website use or tasks conducted. It is clear from the results that VI users put some thought into either dividing the labour in a specific way or to finding some other way to get around the issues encountered

CIS research has defined a number of models which support “asymmetric division of labour”, where each collaborator has a defined role according to their experience (Pickens et al., 2008), role (Morris, 2008) and the availability of computing resource (Amershi and Morris, 2008). For instance Pickens et al. (2008) introduced the concept in their “gatherer and surveyor model”, in which one partner searches for new information and the other partner examines the search results. The strategies used by participants in our study were often of an asymmetric type in which one participant preferred to perform a certain type of task.

It is clear that both the task and condition of the collaborative activity had a great influence on how labour was divided. Moreover awareness and division of labour could not be looked at separately as the level of awareness has a potential impact on the way labour is divided (Morris et al., 2004; McGookin and Brewster, 2007; Metatla, 2010). It was observed that in each of the strategies employed the percentages of the types of information exchanged differed. For instance in the co-located condition the amount of critical information exchanged was higher, as the task was divided in such a way that the sub-tasks were more dependent on each other.

Additionally both the type of awareness information exchanged and the strategy employed to divide labour highly impacted performance of pairs. The more independently individuals performed sub-tasks on their own, the amount of critical information exchanged was lower and the performance was higher in both co-located and distributed conditions. Further the more information that was available to avoid duplication, the higher was the performance in the distributed condition.

5.7 Limitations

In relation to the CIS concepts examined, this study did not investigate the concept of persistence in CIS activities, as this is mainly related to information seeking activities that span a number of sessions, requiring the storage of information between sessions.

In terms of measurements used in the data analysis, some categories identified in the code scheme maybe very much related to the context of the given task. Additionally the observational studies were time constrained, hence not allowing all participants to complete the given task.

The nature of the task in terms of its structure and context is an important factor that can drive the CIS and influences the way the labour is divided (Bruce et al., 2003). The task used in the observational study described in section 3.6.1 is a structured exploratory search task. This was because simple information look-ups and fact-finding tasks typically do not benefit from CIS (Morris and Horvitz, 2007a).

5.8 Chapter Summary

This chapter presents the findings from an observational study carried out with pairs of VI and sighted participants while they collaboratively completed information seeking tasks in both co-located and distributed conditions. The study focused on both the process of IS and the concepts and features of CIS activities. The findings show that though all stages of IS were undertaken individually most of the time, the search results exploration and result management stages were mostly done collaboratively.

There is a clear influence of the different modalities and conditions on both individual and collaborative work. In terms of group awareness the study shows that, given the absence of a common modality, participants were actively notifying each other about their activities and progress. Awareness played an important role in both the strategies chosen and the degree to which labour was divided successfully and efficiently.

Furthermore it was clear that underlying individual IS accessibility issues faced by VI users enforced the adoption of asymmetric division of labour strategies among collaborators. The work was divided between pairs in a way that allowed them to overcome the challenges imposed by cross-modal interaction. In the following chapter, we describe a follow up study to further investigate specific issues that came out of this study. It then discusses implications from study 1 and presents a set of design recommendations for CCIS systems features.

Chapter 6 Study 1: Scenario-based Interviews and Design Recommendations for CCIS Systems Features

6.1 Introduction

The findings of the previous study explicitly highlighted the fact that not surprisingly, there are issues that come out of the cross-modal nature of the examined CIS tasks. In particular these issues were evident in the result exploration and management stages of the process. In order to further examine the issues arising out of the observational study, 7 visually impaired and 7 sighted participants were interviewed individually using scenario-based interviews. The findings reported in study 1 indicate a need to support the process of CCIS, and that the tools currently in use do not adequately address these requirements. We are not aware of any other research that has addressed this problem.

Following a description of the scenario- based interviews this chapter discusses possible implications of the findings of both studies; it also presents possible design recommendations for technical solutions to support CIS in a cross-modal context. It is important to assert here that the presented design recommendations are not intended as general guidelines for the CCIS development community. The main goal of the design recommendations presented in this chapter is to inform the design or modifications to the design of a system that supports CIS, so that it also supports cross-modality. More general guidelines towards the universal design of systems to support CCIS are included in chapter 10, some of which are influenced by the design recommendations of the present chapter.

6.2 Scenario-Based Interviews

6.2.1. Aim

The goal of the scenario-based interviews is to understand how people typically share retrieved information from the web, and subsequently organize and store that information. We are particularly interested in techniques used, tools employed and the content of the information shared. Additionally, we investigate the way information is organized both for individual and collaborative use.

6.2.2 Method

Scenario-based interviews allow exploration of the context of the task, along with discussions of the actions of the users. The story telling approach provides a natural way for people to describe their goals and the actions they take to achieve them in a given task context. Understanding why people do things in a specific way to achieve a goal allows us to concentrate on the human side of the activity rather than the user interface. This allows us to explore the context, constraints, facilitators and challenges. This type of scenario narrative approach is widely used as a means of requirements gathering (Rogers et al., 2011, p. 230). In the context of inclusive design and in particular designing for VI users (Metatla et al., 2011) and (Sahib et al., 2013) have examined the use of scenario-based approaches in the early stages of designing a prototype.

Scenarios are adaptable and can be used at different stages in usability work. Bodker (2000) discussed three ways in which scenarios could be used; to generate thoughts and ideas about a particular situation, at the starting point of a design process or to establish usability evaluation for prototypes. Scenarios allow users to envision the interaction with the interface, explain issues they encounter and recommend changes to interface components. This is particularly useful if the designer is designing an interface for a multimodal or cross-modal system (Sahib et al., 2013). In this study scenarios are used to understand a situation and to identify how participants would carry out a certain tasking using the applications they normally use. The scenario facilitates participants to discuss thoughts about interacting with the applications they use, and the challenges that they encounter.

In this study the scenario-based interview starts by the interviewer describing to the participant a situation that involves a CIS activity. This is followed by four scenarios. Each scenario usually contains two or more questions and is formulated to investigate a specific aspect of the information management process within the overall context of CIS activity. We are interested in exploring these situations for both co-located and distributed settings. Following the questions in the scenario, participants were encouraged to describe a situation in the past that involved CIS activity, allowing them to relate the scenario they were given to a real life experience. A guide to conducting the interviews is given in Appendix B.5.

6.2.3 Participants

We recruited seven VI and seven sighted participants for the interviews. All of them took part in the observational study described in Chapter 5. The interview lasted 25-30 minutes. Participants were not given any compensation. A total of seven VI and Seven sighted participants were recruited between the ages of 21 and 55. Demographic information can be found in Table 6.1. All the participants were regular to very experienced web searchers who conducted web searches on a daily bases using computers and smart mobile devices. All of them mentioned some involvement in collaborative web search activities either with colleagues, family members or friends at least once in the previous month.

	VI Participants	Sighted Participants
Age	1 (21-29), 2 (30-39) 3 (40-49), 1 (50-59)	4 (21-29), 2 (40-49), 1 (30-39)
Gender	3 Male, 4 Female	4 Male, 3 Female
Assistive technology used	All 7 used the JAWS screen reader.	N/A
Browser used	7 IE, 2 Safari	4 IE, 2 Firefox 1 Safari, 1 Google Chrome
Frequency of CIS activity	1 once a week, 1 once a month, 5 once in the past six months	2 weekly, 2 once a month, 3 once in the past six months.

Table 6.1 Demographic information of interview participants.

6.2.4 Findings

In this section, an analysis is presented of the findings from the interviews. We were particularly interested in how retrieved information is kept and shared within a CCIS context. As described in section 3.8.1, similar to the analysis of study 1, we used Grounded Theory (Corbin and Strauss, 2008) to identify concepts from the recordings of the interviews and to devise a coding scheme according to the commonalities in responses across different participants. We divided the analysis into four main issues that arose from the coding of the interviews: content of information kept and shared, tools used, challenges highlighted and approaches used to structure retrieved information.

The Content

There were actually no differences reported between VI and sighted interviewees answers in terms of the content they keep or exchange about the information retrieved. In regards to the type of information kept by individuals, in the majority of cases users chose to store links and details about these links. Some interviewees mentioned keeping or recalling query terms. Others pointed out that they sometimes just keep the websites URL without any notes, particularly if the URL has enough semantic information. The least common techniques were saving the URL as a bookmark or favourite during web browsing or copying and pasting webpage content.

Previous studies reported similar results; in a recent study by Tao and Tombros (2013) the most common reported technique was keeping website links only. Jones et al. (2001) reported that the most frequent method recorded was emailing web links with comments to themselves. A similar finding was revealed by Capra et al. (2010) in which they interviewed people about information re-finding. Whereas in the study by Sahib et al. (2012), the most common technique was copying and pasting links and descriptions from the search results page. The next most common technique in the study by Sahib et al. (2012) was making a note of the query terms used.

With regard to sharing information, similar to the results reported in section 5.5.6, the majority of the information exchanged comprised links with details about their contents. However users also copied and pasted parts of webpages, but that was very rare. One sighted participant indicated that he would copy the parts of a webpage into a document. This confirms the results of a recent observational study on a group of 3 collaborators who performed CIS activities in a distributed setting. In this study the most common technique used was sharing web links with comments about them (Tao and Tombros, 2013). We are not aware of other CIS studies that investigated the content of information kept or exchanged by participants; however a number of developed solutions such as SearchTogether (Morris and Horvitz, 2007a), CoSense (Paul and Morris, 2009), and Coagmento

(Shah and Marchionini, 2010) provide features or dedicated views to store and comment on search results.

The Tools

The interviewees identified several tools that they have used or have seen used for collaboration. In general, the choice of tools by our respondents depended on their situation (co-located or distributed), the objective of the search (work related or family related) and sometimes also the urgency of the matter. Smart phones being were also widely used, and three VI and five sighted interviewees mentioned using their smart phones during collaborative searches.

Email communication was the most frequently mentioned tool in both groups. Even when the interviewees mentioned other tools for sharing information such as Dropbox[19] - a website that offers cloud storage and file sharing and synching services - or specialized note taking and sharing applications, email communication seemed to be the first option that came to mind. Email communication is a common finding across many surveys (Turner, 2010; Capra et. al., 2011; Morris, 2013).

When the process of collaboration involved more than one search session, sighted interviewees described that they would definitely move from email communication for CIS activities to a more suitable tool that will help in synchronizing, sharing, storing and perhaps structuring the information retrieved. The case was quite different with the VI group. Only three interviewees suggested that they would probably use a tool and the rest stated that they will continue using emails. The tools mentioned by sighted interviewees were Google documents[20], DropBox, EverNote[21] and an Apple note taking tool. The only tool mentioned by VI interviewees was Dropbox where two participants commented on finding it a fairly accessible tool, similar to a set of shared folders on a network.

[19] https://www.dropbox.com/en/
[20] https://www.google.com/docs/about/
[21] https://evernote.com/

Using phones was quite a popular answer in the sighted user group we interviewed. Five out of seven suggested that they would probably call their partner in the task and discuss the search results while viewing them. This is in agreement with previous surveys (Morris, 2008; Capra et al, 2011) which identified phone calls as the second most common tool in a CIS process. Interestingly none of the VI users mentioned the use of a voiced phone call during the process. Two VI interviewees mentioned the use of voice calls in Skype. Both emphasized that they would use headsets to ensure that the voice call would not interfere with the screen reader. When asked about the option of making a phone call to discussed retrieved information, all VI interviewees mentioned it would be the least favoured option. A phone call introduces an additional audio stream, which can slow down the process as the VI participant would need to listen to both the screen reader and partner on the phone.

Instant messaging was equally mentioned by both groups. Using social networking for direct communication with partners was also mentioned by three VI and two sighted interviewees. Twitter was the social networking tool mentioned the most. Interviewees said that they would share the retrieved information by either sending a direct private message to their partners using Twitter or by simply posting a tweet with the link to be shared. Two VI interviewees stated that they think it is a faster way to communicate than email. All of the interviewees are smartphone owners and reported they quite often use their smartphones to look up information. This behaviour was surprisingly frequent in each group. Specialized applications such as EverNote and Instapaper[22] were used by both VI and sighted users for individual information seeking.

The Challenges

Both VI and sighted interviewees reported challenges related to the process and the need to use multiple applications to perform CIS. VI users also highlighted the challenges related to web accessibility. Challenges related to the process were mainly associated with the lack of available

[22] https://www.instapaper.com/apps

tools. Interviewees reported many frustrations around the need for a tool that would facilitate the process and said they were unaware of a tool that allows URL sharing and storing. Even though such tools are becoming increasingly available. These include free online CIS tools including Coagmento (Shah and Marchionini, 2010) and So.cl (Farnham et al., 2012) or social bookmarking websites such as Diigo[23] and Bing toolbar.

The issue of the lack of a single, integrated tool to support this type of collaborative activity forces the collaborators to combine the use of a number of tools in order to perform collaborative search and sense making, as discussed in the previous section. Since mainstream web browsers and search engines do not incorporate a means of communication where users can share and discuss web search results interactively without actually leaving the browser, all the interviewees chose to use two or more tools to perform the process. The main preferred tool was email and the second preference was one out of instant messaging, voice call, a social networking site or even a share document or folder. One of the VI interviewees - who used Twitter to exchange information with collaborators -, suggested that a tool would be efficient only if it was as fast and as easy as sending a direct message in Twitter.

Accessibility issues when encountering web components were mentioned by VI participants. The serial nature of screen readers can slow down the web search process of VI users, as evidenced by an interviewee who pointed out that she sometimes delegates tasks that involve lots of web search activities to her personal assistant (PA), asking her PA to provide her with a concise list of search results. Interestingly, some of the individual challenges could be considered as a trigger for a collaborative search. One interviewee mentioned that one of the reasons behind engaging in collaborative web search activities with her PA is the likelihood of finding inaccessible web components during her web interaction, at which point she would need the assistance of a sighted user. Another VI user highlighted that he preferred to perform online shopping with his sighted partner as some products do not have sufficient descriptions attached to the images.

[23] https://www.diigo.com/

Cross-modal interaction can also pose numerous challenges on the activity as reported in the results of the observational study. The difference between the webpage structure rendered by the screen reader and the visual structure of the webpage was an issue that was frequently reported by all the VI interviewees. They described it as a frustrating process due to the sighted partner not knowing where the attention of the VI user is currently focused when collaborating in a co-located setting. All VI participants believed that a shared display in a co-located setting would be of no use given that this issue is always present with screen readers such as JAWS. However one VI interviewee stressed that when taking part in co-located collaborative activity, she prefers using Apple's Voiceover screen reader where the words being read by the screen reader are highlighted. This allows her sighted partner to know the web region she is viewing. For the majority of screen readers, where this is not the case, the differences in representation can certainly affect the sense making process, as it requires effort from both the VI and sighted partners to reach a mutual understanding of the on-screen focus of the VI user.

The Structure

The final part of the scenario-based interview investigated the ways in which retrieved information is organized and kept for later use, and the approaches used to structure and categorize retrieved information. The main difference found between the two groups was their tendency to put information into categories. While all the sighted interviewees tended to prefer creating categories in a hierarchical way to store retrieved web information, six out of seven VI users preferred storing the retrieved information in a flat list. The sighted participants stated that they usually categorize retrieved information by subject. Furthermore they all asserted that according to their own experience, when it comes to web search results, the depth of the hierarchical structure would rarely reach three levels (depending on the topic).

This was not the case with the VI users with six of them favoured using flat lists over categories, putting the most important web search results at the top. This ordering behaviour is perhaps not so surprising given the serial nature of screen readers. The longer the list, the more time the user will spend to reach the bottom of the list, hence they tend to place the most frequently used or the most important websites at the top. One VI interviewee explained that after years of experience with the web, she developed a mechanism to categorise stored websites by assigning a number for each category. For instance she assigned one to medical-related websites and two to book-related websites. Though it is a flat list, the information is classified where each category is assigned a number and each number is placed in front of the stored URL which belongs to a specific category. Another VI interviewee described a fairly similar numbering approach to categorizing and prioritizing retrieved information. Storing retrieved information in lists that are chronologically ordered was also mentioned by two VI interviewees.

6.2.5 Summary of the Findings from the Scenario-Based Interviews

This follow up study investigated the ways people manage and share information retrieved from the web. The scenario-based interviews approach helped us in knowing that collaborative search is quite a common practice as all the participants were able to relate the given scenario with similar activities they had undertaken in the past. The study also found that often ad hoc combinations of everyday technologies are used to support this activity rather than the use of dedicated solutions. There were clear instances of the use of social networks to support the sharing of retrieved results.

Individual and cross-modal challenges were also extensively mentioned by VI interviewees, as current screen readers fall short of conveying information relating to spatial layout and helping users form a mental model of webpages congruent with that of their sighted partners. It is clear that the VI participants interviewed were fully aware of the drawbacks that the serial nature of screen readers impose on their web search activity. In fact, these challenges have led them to choose to perform some web search activities collaboratively when that was an option. In the interviews, sighted participants often mentioned the use of tools that provided rich structuring mechanisms to handle information retrieved from the web, whereas VI users preferred using flat lists.

6.3 Design Recommendations for CCIS System Features

The results of study 1 and the follow-up interviews identified the following issues faced by the pairs of users taking part in CCIS:

- The need to use multiple applications, leading in turn to frequent application switching. While this is true for both sighted and VI participants, the overhead is more significant for VI users as doing this from the keyboard is rather slower than with a mouse.
- The lack of a shared, structured set of results available to both partners.
- The need to provide explicit awareness information about task progress and the updates in the shared workspace.
- Issues in scanning large sets of results on the part of VI users.
- Issues relating to individual web component accessibility for VI users.

These last two issues tend to lead in turn to asymmetric divisions of labour, with sighted partners taking on more tasks than their VI peers. This section examines how the issues identified here specific to individual and collaborative IS might be addressed. Specifically we do not address here issues of web component accessibility per se, as the focus of this thesis is on CIS. In addition to confirming the issues highlighted by Sahib et al. (2012) and Craven and Brophy (2003), this section focuses on issues that are more likely to affect collaborative interaction. An important element of this section, and contribution of the thesis, is the design recommendations for CCIS system features proposed. The justification for these design recommendations for CCIS system features is based on the evidence from the results of study 1 and the follow up interviews. Nevertheless, many of these design suggestions are untried, and so we offer them as potential solutions to the problems revealed by the study and follow up interviews. We do recognise that they may be implemented in many different ways and that any specific implementation must be subject to careful evaluation, both as an effective solution to the problem that gave rise to it and for its impact on related areas of the CIS process. In this sense what we propose here is towards an agenda for research in the design of systems to support CCIS.

6.3.1 Improving the Accessibility of Information Seeking

Providing an Overview of Search Results

Search results exploration was mostly done collaboratively. The reason behind this sort of collaboration is that the VI participants needed help from their sighted partners to navigate through a large volume of search results. This also was highlighted by studies that compared VI individual information seeking behaviour with sighted information seeking behaviour (Ivory et al., 2004; Sahib et al., 2012). These studies have stressed that this stage is the most challenging and time consuming for VI users. In fact, this stage was assessed to be twice as long when performed by VI users rather than sighted users (Ivory et al., 2004). The sequential nature of speech rendered by screen readers can overload the user's short-term memory and provides no means of representing spatial layout and contextual information of webpages (Murphy et al., 2007b).

Developing a mechanism that provides VI group members with an overview of search results and the ability to focus on particular pieces of information of interest could help in increasing VI participants' independence during CCIS activities. Studies by Shneiderman (1996) and Marchionini et al. (2000) support the idea of structuring the process of visual information seeking by providing the user with an overview of information followed by the option of viewing the information in detail. Shneiderman's (1996) Visual Information Seeking Mantra is described as: "overview first, zoom and filter, then details-on-demand". The principle he presented was then extended by Zhao et al. (2004) to fit the auditory environment where they developed the Auditory Information Seeking Principle as: "gist, navigate, filter, and details-on-demand". Marchionini et al. (2000) suggest that information seeking interfaces can be improved by structuring them according to six views; a primary view, overview, preview, review, peripheral view, and shared view of an information space (e.g. an online library, a document collection etc.), a primary view shows a segment of the space (e.g. a document) in its full detail. An overview provides a summary of all the documents in the space. A preview gives information about a single document reachable from the current document (e.g. by following a link) while a review gives a history of documents visited. A peripheral view shows documents semantically related to the one currently under investigation in the primary view. A shared view presents information about visits to documents by other users. Parente (2003) explored the idea of audio enriched links. He developed and evaluated a JAWS screen reader script which, in response to the user clicking a hyperlink, presented a speech-based summary of the webpage. This summary includes the title of the webpage, statistics about its content and a collection of headers available in the webpage.

Efforts to develop auditory overviews of search results can also benefit from the vast amount of information retrieval research related to filtering and navigating search results (Hearst, 2009). Given the development of such an overview mechanism, VI web surfers are likely to perform the results exploration stage more effectively and efficiently, as they could firstly get a gist of results retrieved and can then drill down for more details as required. This could help VI collaborators to work more independently by speeding up their search exploration process, hence allowing group members to manage their resources and labour more efficiently. This will advantage both individual and collaborative information seeking activities.

Design recommendation for CCIS system features 1- Include an auditory overview of search results and possibly a mechanism to zoom in to a particular subset of results.

Design recommendation for CCIS system features 2- Add mechanisms for filtering and grouping or clustering search results to make the process of navigating through results using a screen reader faster.

Design recommendation for CCIS system features 3- Facilitate sharing of search results between collaborators. The user who wishes to share results could send an alert to their partner and then share the search results currently being explored. This feature should also show the results that are already explored in an attempt to avoid any duplication of effort. This would deal with the situation where VI searchers wish to get help from their sighted collaborators to process search results but it also more generally facilitates results sharing, discussion and decision making based on retrieved results. This is an example of a design feature whose origins lay in a requirement to improve accessibility but that brings genuine benefits to all users.

Improving the Management of Search Results

As observed in the study and discussed in the post-study interviews, managing search results was one of the main obstacles faced by VI users during CCIS activities. This was more apparent in the distributed condition where the user was required to switch between three different applications and thus spent significantly more time switching between them. Moreover, study 1 and the follow up interviews highlighted differences in individual approaches employed by sighted and VI users when managing search results. Improved support for this stage could significantly contribute to enhancing the effectiveness of collaborative activity.

A recent study by Sahib et al. (2013) described an integrated tool that allows VI users to keep track of search progress and manage search results. An evaluation of the tool with VI participants resulted in high satisfaction rates as they found it easier to handle search results within the tool as it removed the overhead of switching between a number of applications. Having one integrated interface has the potential for reducing workload during a CIS task.

Design recommendation for CCIS system features 4- Provide an integrated solution that allows collaborators to search the web, share and store retrieved information and communicate without the overhead of switching from one application to another.

6.3.2 Improving Cross-modal Collaborative Information Seeking

The study highlighted important issues specifically in regards to improving cross-modal collaborative information seeking. It can be inferred from the findings that there is a clear need to maximise the sharing and management of information between collaborators in a cross-modal environment. Improving awareness in the context of information seeking would be of great benefit. Very few studies have explored supporting awareness in an accessible cross-modal collaborative context (Winberg, 2006; Metatla, 2010). This section will reflect on our findings in improving the sharing and managing of retrieved search results, in addition to facilitating workplace awareness in the context of this process.

Improving the Sharing and Management of Search Results

From the observations there is a clear need to improve the sharing and management of information between collaborators. A utility that allows collaborators to recall visited websites and query keywords entered by their partners is clearly not sufficient, as our findings showed the majority of information exchanged regarding search results included website links and details of the information retrieved. Therefore, a tool to support CCIS needs to provide better integration of the whole process as well as supporting the sharing of websites and details of results found. A tool like SearchTeam[24] which is a commercially available website for collaborative search, provides the collaborators with a common place to share details of websites, links and comments. This is similar to a feature that Diigo (Kelly and Payne, 2014) a collaborative bookmarking website, provide that allows users to share bookmarks.

Design recommendation for CCIS system features 5- Provide a place to store and share links and comments. The mechanism to store the links and comments should be very easily available (ideally for example a hot key combination) from the point where the link was found or from where the comment was written.

---

[24] http://searchteam.com/

Design recommendation for CCIS system features 6– Provide the ability to tag and rank search results.

We have also observed that in the distributed setting all pairs did not rely solely on the communication tool to keep track of information. In fact, all pairs used external note taking applications such as notepad or Microsoft Word to keep track of results retrieved. Having a common place to save and review information retrieved can enhance both the awareness and the sense making processes and reduce the overhead of using multiple tools, especially in the case of VI users, who do not have sight of the whole screen at one time.

A recurrent theme in both the observational study and the scenario-based study is the tendency to categorize the information retrieved among sighted participants. In fact the studies (Paul and Morris, 2011; Kelly and Payne, 2014) showed that generally participants prefer a more structured way of organizing retrieved information. Moreover, researchers found that searchers also tend to rearrange items as a part of collaborative sense-making (Tao and Tombros, 2013; Kelly and Payne, 2014).

This approach of rearranging retrieved information can be seen in the ViGOR system (Halvey et al., 2010) and in SearchTeam which includes a workplace that allows users to move or drag and drop results into different categories. In terms of individual IS, researchers have explored structuring search results to enable users to make sense of the retrieved information. They suggested the use of tree views to aid the individual sense-making process (Qu, 2003; Morris et al., 2010a). However in the scenario based interviews, the majority of VI interviewees expressed their preference for using flat lists when it comes to storing retrieved information, as the process of navigating through a hierarchy may be quite demanding. They stated that "with lists we can reach the information faster and more easily" [S8, S6, VP]. Three of the VI participants developed their own approach to categorizing information (as reported in section 6.2.5) as a means of avoiding the need to navigate through a hierarchy of results. Studies in auditory displays have identified the weakness of representing structure in speech-only audio (Brewster, 1996; Walker et al, 2006). They proposed and evaluated the use of none-speech sounds to aid the process of tree structure navigation.

Design recommendation for CCIS system features 7- Provide the ability to list or structure the stored information.

Design recommendation for CCIS system features 8- Support a cross-modal representation of lists and hierarchically structured information. This is includes adding features to sort the list of stored information chronologically and the ability to search and tag the stored information.

Design recommendation for CCIS system features 9- Support a cross-modal representation of all changes made by collaborators in the shared workspace. As changes in a visual interface can be represented in colours, changes in the audio interface might be represented by a non-speech sound or a modification to one or more properties of the speech sound, for example timbre or pitch.

Improving the Awareness of Search Query Terms and Search Results

Allowing collaborators to know their partner's query terms and viewed results will inform them about their partner's progress during a task. Additionally, having a view of your partner's search results can allow sighted users to collaborate with their VI partners while going through large amounts of search results. The WeSearch system (Morris et al, 2010) provides collaborators with the means of sharing queries and comments within the group. The queries and comments are colour coded by collaborators. This could be implemented within the context of CCIS by using different screen reader voices and/or spatially distributing the auditory representations of queries and comments made by different group members. A tool like Coagmento (Shah and Marchionini, 2010) provides a mechanism to allow users to be aware of their team members' activities. This is done by dedicating views that are updated with query terms used and webpages viewed by collaborators. CoSense is a Microsoft developed CIS system that is aimed to support sense-making in collaborative web search tasks. It provides the users with different views of the collaborators' activities in terms of query keywords; documents retrieved and shared comments (Paul and Morris, 2009). In the CCIS context, features and views provided by interfaces such as Coagmento and CoSense, could be tailored to be screen reader friendly, by supporting rapid navigation to different views using mechanisms such as shortcut keystrokes, place markers and providing keyword summaries of activities.

Sound has also been used to augment mainstream CIS interfaces in the cases of co-located CIS that used table top displays (Morris et al, 2006; Smeaton et al, 2006; Morris et al, 2010). In these table top interfaces, auditory feedback is used to communicate group members' actions and render different aspects of their shared workplace. These types of interfaces are usually described to be rich in terms of awareness and attempt to decrease the dependency on verbal communication. Though awareness in cross-modal interaction is currently gaining much interest, it has not been explored in the context of information seeking.

Very few studies have explored supporting accessible awareness information in regards to cross-modal collaboration (Winberg, 2006; McGookin and Brewster, 2007, Metatla, 2010; Metatla et al., 2012). These studies primarily examined conveying information about group members' activities using sound in an attempt to improve awareness. The results of these studies indicate that a shared audio output can potentially increase individual and group awareness, thus allowing a better collaboration.

Design recommendation for CCIS system features 10- Provide cross-modal representation of collaborators' current IS activities. These activities include query terms entered, results currently viewed, and results viewed in the past. In a cross-modal context a visual view can be dedicated to these activities and an audio representation could have different non-speech sounds to represent these different activities. These non-speech signals could be followed by providing the VI user the option to listen to keywords entered and explore webpages viewed by their partners. This mechanism could allow VI users to be aware of the activities of their partners. It is important to mention here that mainstream CIS research has extensively examined approaches to providing awareness information of IS activities, as discussed in section 2.5.1.3 of the literature review, however these approaches have not been examined in a cross-modal context.

Design recommendation for CCIS system features 11- Provide cross-modal representation of collaborators' past IS activities. By this we mean displaying a chronological view of previous query terms and websites explored. From a visual perspective this can be a dedicated view, while from an audio perspective the user could perform wider scale navigation using short cut keys and then use cursor keys to navigate between individual results.

6.4 Chapter Summary

This chapter starts by describing a follow up series of interviews that investigated the ways people manage and share information retrieved from the web. The scenario-based interviews approach has helped us in establishing that collaborative search is quite a common practice among the interviewed VI and sighted participants. The interviews identified that often ad hoc combinations of everyday technologies are used to support this activity rather than the use of dedicated solutions. Several instances of the use of social networks to support sharing of retrieved results were reported.

Individual and cross-modal challenges were also extensively mentioned by VI interviewees due to shortcomings in current screen reader technology and inaccessible web components. In the interviews, sighted participants often mentioned the use of tools that provided rich structuring mechanisms to handle information retrieved from the web. In contrast, VI users preferred to use simple lists to store retrieved information, or in some cases had devised their own numbering schemes or orderings of items to support their easy re-finding of information.

The findings reported in this follow-up study and in study 1 (in chapter 5) clearly indicate the need to provide a tool that can enhance the performance of visually impaired and sighted users when undertaking CCIS activities. This chapter discussed the implications of these findings and provides specific design suggestions to consider when developing accessible and usable interfaces to support CCIS. Because many of these suggestions are untried the set of design suggestions put forward can be seen as a research agenda for the design of systems to support CCIS.

Chapter 7 Functionality and Accessibility Review

7.1 Introduction

Our initial exploratory study of the CCIS interaction between VI and sighted users, described in Chapter 5, formed our understanding of the process, its challenges and opportunities. The outcome included the quantitative and qualitative results of the study as well as a set of recommendations for CCIS system features, proposed in Chapter 6. This chapter (section 7.3) starts with surveying and exploring a range of CIS systems to select the most eligible and available tools. In section 7.5 we perform an exercise to map the design recommendations for CCIS system features in section 6.3 to the selected systems' features. Section 7.6 then describes the accessibility evaluation process. Both exercises described in sections 7.5 and 7.6 identify SearchTeam to be the most suitable tool. The factors taken into account in making this decision are described in section 7.7. The chapter continues by introducing the features of SearchTeam in detail in section 7.8. As reported in section 7.4, SearchTeam has got a number of accessibility issues that impact user experience. Section 7.9 discusses the recommended enhancements to be made to improve the user experience and enable the interface to support a number of the design recommendations for CCIS systems features made in section 6.3. Section 7.10 describes the enhancements made to SearchTeam. We named the extended SearchTeam interface Accessible Collaborative Searching Zakta (ACSZ).

7.2 Motivation

Early work in developing and evaluating systems that support CIS mainly focused on enhancing searchers' experiences in libraries. Twidale et al. (1997) built and evaluated an interface that supports collaborative searches on the Lancaster University library database. Following the Morris (2008) survey, a number of general purpose and specialized purpose CIS interfaces were built and evaluated. Very few were made available for public use, or even for further testing. We conducted a survey to find the available systems, examine the features they provide and ways these features can be extended to support cross-modal use. The main purpose of this exercise was to choose an interface which has features that support, or can be enhanced to support, the design recommendations for CCIS system features (documented in section 6.3) from our first study and follow-up interviews. This will allow us to evaluate CCIS activity using an interface that goes at least some way to support it. There are a number of reasons this approach was chosen:

1. The aim of this thesis is to develop an understanding of CCIS activity and inform the design of an interface that specifically supports it. From performing our initial literature review, we already knew that there are a number of interfaces that were available online, and that using one or more of these interfaces was an option. The recent flurry of CIS interfaces development has encouraged researchers to examine them in different contexts. A recent study by Kelly and Payn (2014) evaluated two collaborative search tools: Coagmento (Shah and Marchionini, 2010) and Diigo[25] in real-world environments, where they asked participants to use both interfaces for an extended period of time. Wilson and Schraefel (2009) used Morris and Horvitz's (2007a) SearchTogether in evaluating the process of CIS to re-assess an individual framework for IS. Coagmento has been used in a number of studies (Shah, 2009, Shah, 2010a, Shah and González-Ibáñez, 2011, Wu and Yu, 2015, Kelly and Payne, 2014) in evaluating different aspects of the CIS process.

2. Technical feasibility was another reason that led us to choose this approach. Building a cross-modal CIS interface that supports the design suggestions presented in chapter 6 was not technically viable with the resources and time-constraints of a single PhD project.

3. We wanted to follow an inclusive design approach, as much research, especially in the last two decades, supports the concept of 'inclusive design' (Hypponen, 2000; Newell et. al, 2011). Inclusive design aims to design interaction to serve diverse users (Clarkson and Keates, 2003). The introduction of concepts such as 'inclusive design' and 'universal usability' and the development of

[25] https://www.diigo.com

W3C work in the field of accessibility have brought about improvements in website accessibility (Meiselwitz et al, 2010). We had a clear preference for improving the accessibility of an existing system to be used by both VI and sighted users, rather than developing a separate site for a specific group of users.

For the above reasons, the decision was taken to use an existing mainstream CIS system, providing of course that one was available with an adequate level of accessibility, or that could be adapted to be accessible.

7.3 Survey of Available CIS Systems

To be congruent with the work of study 1, we needed to find a CIS interface that supports both co-located and distributed collaboration; therefore table top interfaces were excluded, such as TeamSearch (Morris et al., 2006), Físchlár-DiamondTouch (Smeaton et al., 2006) and WeSearch (Morris et al., 2010a). The interface was required to support general purpose CIS. To improve relevance, we wanted to observe users searching the World Wide Web; therefore we excluded interfaces that supported searches in one specific domain, such as Ariadne (Twidale et al., 1997) and QuestionPoint for library searches, interfaces that support literature searches such as Zotero[26] Groups and interfaces that support specific document sets such as Queruim (Golovchinsky and Diriye, 2011). Similarly interfaces that support specialised searches - such as C-TORI that support relational database searches (Hoppe and Zhao, 1994) or COSME that support developers in searching computer program code (Fernández-Luna et al., 2010) - were not considered. Additionally the search tasks we were going to use would not explicitly include multimedia searches, so we were not interested in interfaces that supported multimedia-only searches such as VIGOR (Halvey et al., 2010) and Cerchaimo (Pickens et al., 2008)). Similarly, mobile interaction is not the focus of this thesis, therefore Co-Search (Amershi and Morris, 2008) and the mobile versions of Diigo and Coagmento (Shah and Marchionini, 2010) for iPhone and android Operating

[26] https://www.zotero.org/groups/

Systems, were not included. Although participants indicated in the scenario-based interviews that they sometimes used social networks in searches, social media systems are not within the scope of this thesis, therefore interfaces such as SearchBuddies (Hecht et al., 2012) and Bing toolbar (Shum and Connell, 2012) were not considered. The design recommendations for CCIS system features in chapter 6 focused on general-purpose CIS interfaces that support distributed and co-located collaborative searches.

7.4 Discussion of Considered CIS interfaces

A number of research-based and commercially-based interfaces were identified. These interfaces represent a diverse set of characteristics, architectures and features. This section provides a brief description of each interface.

SearchTogether

Following her important survey (Morris, 2008), Morris and Horvitz (2007a) designed SearchTogether to support the process of CIS in distributed environments. SearchTogether is an IE plug-in that allows collaborators to communicate via a chat tool, view collaborators search histories, rankings and recommendations. It also supports collaborative search engines that allow users to choose the type of search required. It provides three types of search: standard search displays the results only for one collaborator; split search retrieves the highest-ranked search results by other team members; "Multi-Engine Search" sends the results to all the collaborators available online. To initiate CIS activity, Search Together prompts users to create a session and invite team members to each project. A user can have multiple sessions with different team members in each session. The system also supports asynchronous collaboration by preserving collaborators' activities in chronological order.

CoSense

CoSense is an extension to SearchTogether built by Paul (2009) as part of her PhD work. The main purpose of CoSense is to support sense-making in the process of CIS. It provides the user with four different views: a search strategies view, a timeline view, a chat-centric view and a workspace view. The search strategies view provides users with an insight into their team members' search activities that includes query terms used, websites visited and use of a special search engine provided by SearchTogether. The timeline view provides a view of collaborators' activities in chronological order. The chat-centric view contains both a chat instant messaging service and a browser that allows collaborators to see the activities of team members at the time they send a message. The workspace view is a place in which collaborators save their notes in a flat list structure.

Coagmento

This system was developed by Shah (2010a) as a part of his PhD work as a standalone system, and it was subsequently redesigned as a Firefox and Google Chrome browser plugin that supports distributed CIS. It provides two components; a toolbar and sidebar. The toolbar has buttons for adding bookmarks and annotating a webpage. It also provides users with an overview of search results (viewed and annotated). The sidebar is composed of four main sections; the chat section, the resources section which stores saved queries, bookmarks and files, the notepad section for users to store and share notes, and the notification section which is a mechanism to provide awareness information about the search activities of team members. Coagmento allows users to create several projects with different collaborators; a user can specify a project name and invite project members. In Coagmento a project is referred to as CSpace which is a webpage that a user can access. A CSpace includes a history of all webpages visited by team members.

S3

S3 allows collaborators to share web search results in a persistent file format that can be sent and augmented by multiple users; a special browser is designed to support the use of S3 files (Morris and Horvitz, 2007b). The browser records queries entered, search results viewed and webpages visited. The browser consists of two parts: the web browser and the session summary. Users can add comments to search results. The session summary includes an overview and a detailed view of collaborators' activities. The overview shows the users' queries and pages visited, while the detailed view provides additional information such as title, snippet, URL, thumbnail, the name of the user who viewed the webpage and comments associated with it.

SearchTeam

SearchTeam is a real-time collaborative search engine, which is specifically developed to help users when performing CIS tasks on the web. SearchTeam is a product of Zakta[27] which is a social intelligence platform which provides a number of applications to support marketing research on the web, collaborative searching and social learning. In SearchTeam, each collaborative search task is conducted within what is called a SearchSpace. In a SearchSpace collaborators search the web together and save and edit their results in the SearchSpace. They can invite unlimited numbers of collaborators to each SearchSpace. There is a persistence feature where the collaborators can work asynchronously and pick-up from where their team members left off. Results are organized into user-created folders within the SearchSpace. Within these folders, collaborators can comment on search results, "like" them, add posts, or upload documents. The search results page also allows users to save results directly to folders. Collaborators can see their team members' updates in the folders via a recent activity region. SearchTeam also provides an embedded instant messaging tool.

Diigo

Diigo is an abbreviation for Digest of Internet Information, Groups and Other stuff. It is a web tool that allows personal and collaborative bookmarking. It was developed by a team of software developers and its main feature is bookmarking and web-page tagging. It also allows users to highlight any part of a webpage and attach sticky notes to specific highlights, or to a whole page. These bookmarks and annotations can be kept private, shared with a group within Diigo, Facebook,

[27] http://zakta.com/about.php

Twitter or a special link forwarded by email. It is basically a toolbar that can be added to the IE or Firefox web browser. It allows the user to send web search results to their followers who are registered Diigo users, or to a specifically user-created group. Their followers or a group member can then comment, "like" or save the links.

Research-based CIS interfaces are rarely made available after a project is completed; interfaces such as CoSense and S3 were never made available. SearchTogether was available until Microsoft withdrew its MSN messenger product in March 2013. MSN messenger IDs were used to login to search together which meant it could no longer function. Coagmento continues to be made available for public use. In fact, it has developed into a framework that supports the development of CIS interfaces by allowing developers to change, add or remove different Coagmento components to support CIS in different contexts and settings (Shah, 2010a). Thus Coagmento, SearchTeam, and Diigo, were considered as viable to investigate their suitability for study 2. Figures 7.1, 7.2, and 7.3 respectively show screen shots of the three interfaces.

From the literature search described in Chapter 2, and the recommended CIS system features in section 6.3, we compiled the main components and features needing to be supported in table 7.1. We use the acronym RECx to refer to the design recommendation of CCIS system features in section 6.3 where x indicates the number of the design recommendation. In the next section design recommendations for CCIS system features summarised in table 7.1 will be examined against the features provided in Coagmento, SearchTeam and Diigo.

Components	Recommendations for CIS system features	Description
Information Seeking	REC4 an integrated solution that allows users to search the web	Basic search engine functionalities (Russell-Rose and Tate, 2013) and results displayed.
	REC1 auditory overview	An overview of the search results
	REC2 Adding features of filtering and grouping	Allow users to filter and cluster information
Results Management in shared workspace	REC 5 Storing and Sharing links and comments	Shared workspace to store comments
	REC6 The ability to tag and rank search results	Stored links can be ranked, liked and tagged by collaborators
	REC7 The ability to structure and list stored information	Provide mechanisms to manage information in a structured way
	REC8 A Cross-modal representation of stored structure	A mechanism to render structure via visual and audio-cues
	REC4 an integrated solution that	An integrated messaging system that supports real-time communication during a

Awareness of IS process and workspace	allows users to communicate.	search session
	REC3 Sharing current and previous search results page	Ability to view collaborators’ search results page
	REC 10 Providing a cross-modal representation of collaborators current IS activities.	Ability to view collaborators’ IS activities which includes query terms and webpages currently viewed. Providing a mechanism to quickly navigate through them for both visual and audio cues. Including visual and audio alerts to signal these different activities.
	REC 11 Providing a cross-modal representation of collaborators’ historic IS activities displayed chronologically.	Ability to view collaborators’ IS activities which includes: query terms and webpages previously viewed. Providing a mechanism to quickly navigate through them for both visual and audio cues
	REC9 A cross-modal representation of changes that happen in the shared workspace	Updating the users using cross-modal alerts to changes in the workspace.

Table 7.1 Recommended main components and features for CCIS systems.

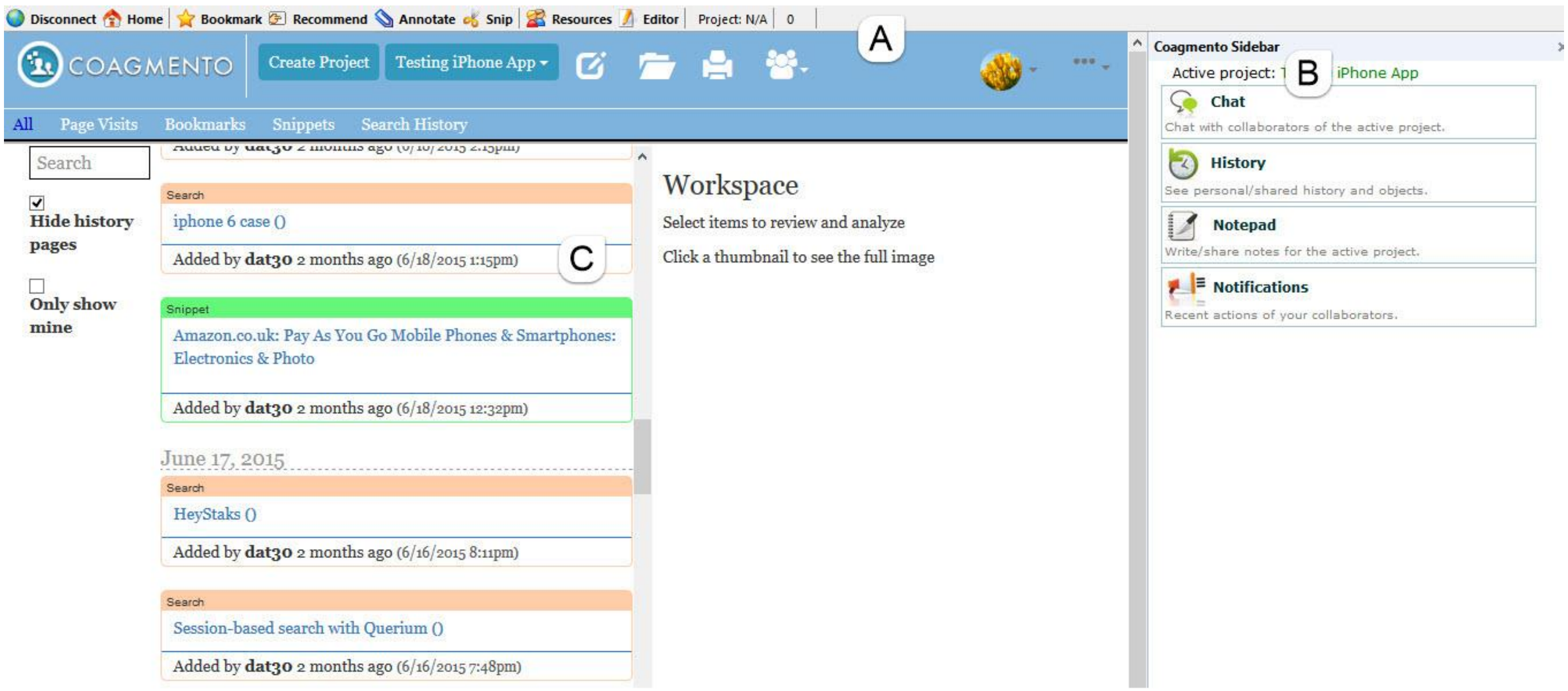

Figure 7.1 The Coagmento interface.

(A) The Coagmento toolbar. (B) Sidebar providing chat, history, notifications, and a notepad. (C) The CSpace shared history.

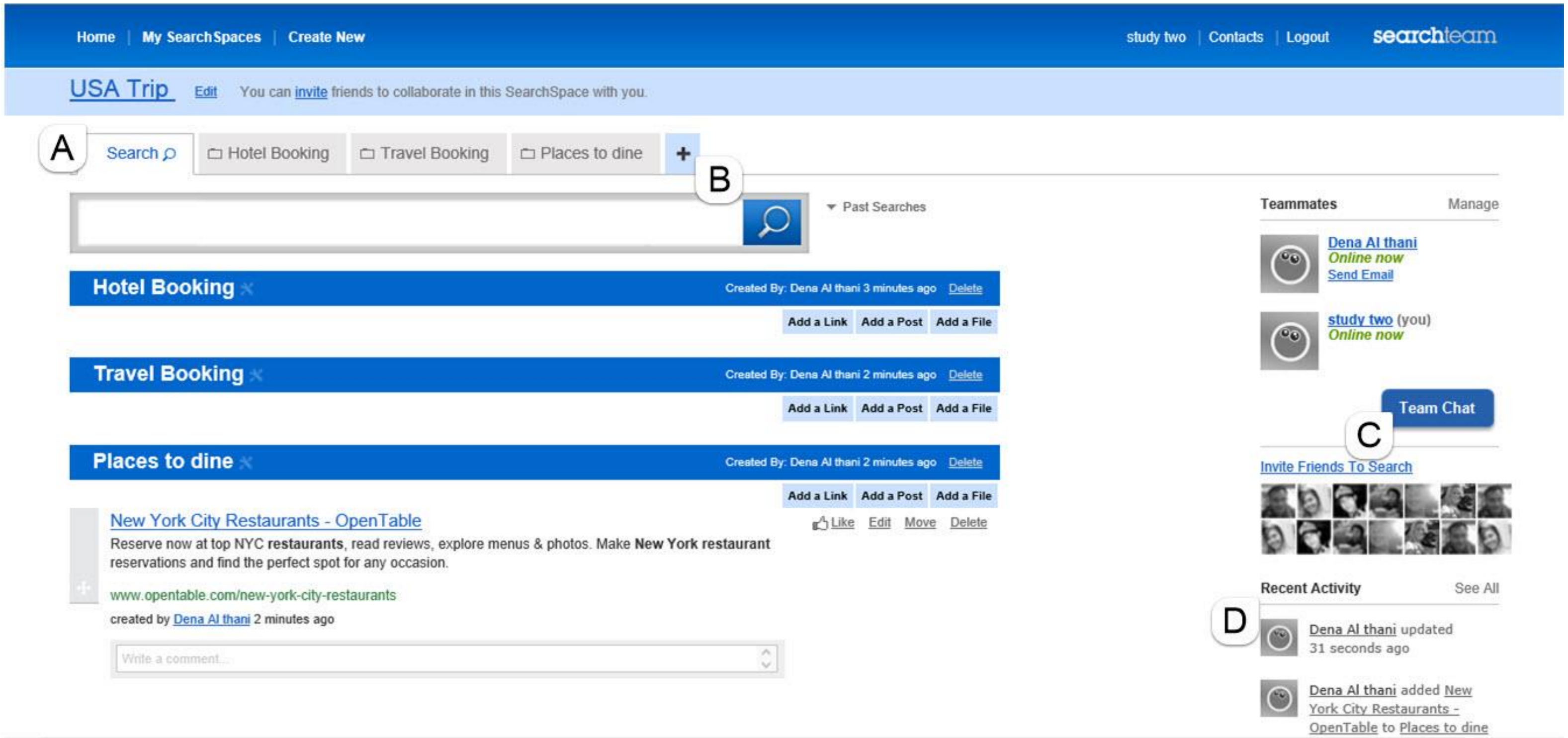

Figure 7.2 The SearchTeam interface.

(A) Search engine tab. (B) Create new Folder Tab. (C) Team chat button to open the team chat modal dialogue form (D) Recent activity region.

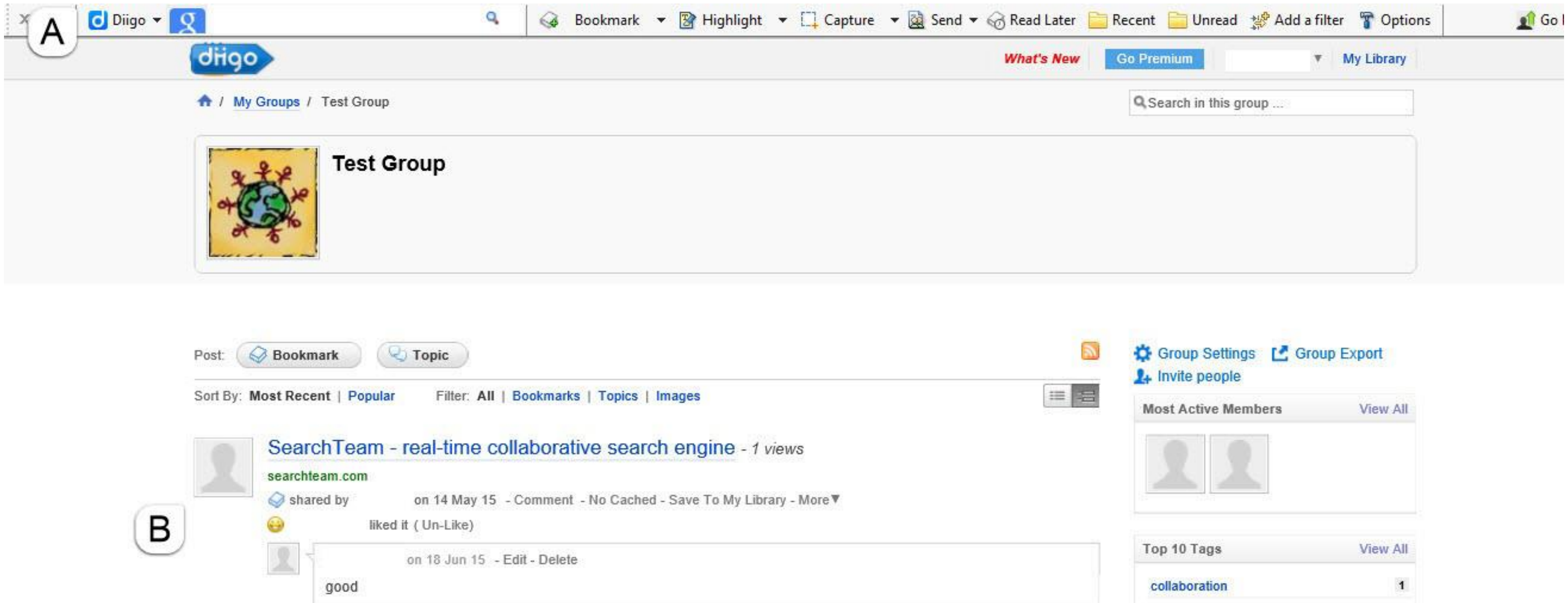

Figure 7.3 The Diigo interface.

(A) The Diigo toolbar. (B) Shared history of store topics and bookmarks.

7.5 Functionality review

In table 7.2 we perform an exercise of mapping the selected interface features to the system components and recommendations for CCIS system features summarized in table 7.1. It is worth mentioning here that we knew from the start of this review that the choice of the interface to be used was always likely to be a compromise. Whilst the recommendations for CCIS system features are predominantly focused on cross-modal and accessible interaction, none of the mentioned interfaces were designed with cross-modal accessible interaction or with accessibility specifically in mind. Thus, the chances of them supporting, or being modifiable to support many of the recommendations for CCIS design features described in section 6.3, was remote. What was intended therefore was to find a system that was relatively accessible, and that was modifiable to some degree to improve its support for CCIS. The exercise in this section is primarily aimed at reviewing the functionality of the selected interfaces by evaluating the availability of identified CIS components and features. Section 7.6 then reviews the accessibility of these interfaces in attempt to choose the most accessible one.

Components	Design recommendations for features	Coagmento	SearchTeam	Diigo
Search	REC 4 An integrated solution that allows users to search the web together	This feature is not available in Coagmento. The user has to use the search engine and use the toolbar to store bookmarks. However in Google Chrome the user can simply right click on the page and choose 'Bookmark' from the Coagmento menu.	SearchTeam has an embedded collaborative search engine that allows users to search and view search results within the interface	This feature is not available in Diigo. The user has to use the search engine and use the toolbar to store or share the bookmarks with collaborators.
	REC 1 Overview of Search Results	This feature is not available	This feature is not available	This feature is not available
	REC2 Filtering and grouping or clustering search results	It does not have a search engine. However the workspace (Project) provides a means of clustering retrieved information	It provides bars, circles and maps in the Search Engine page within a Space. The search results can be filtered and grouped.	This feature is not available
Results		This component is available, it is	This component is available, it is	This component is available, it is

Management in shared workspace		called "CSpace" in which users are allowed to create CSpace and add members	called "Spaces" in which users are allowed to create "Spaces" and add collaborators to the project.	called "Groups" in which users are allowed to create Groups and invite members.
	REC 5 Storing and Sharing links and comments	In the Firefox toolbar or menu in Google Chrome, a user can "Bookmark", "Snip" and "annotate" or "Recommend". In the Sidebar users can view bookmarks, snip and annotate. In "CSpace", users can view bookmarks, snip, annotations.	Users can use the "Save button" next to search results. Users can "Add posts", "Add links", "Add files". Users can "comment" on the added posts, links, or files.	This feature is available in both the browser toolbar plugin and the web interface. On the toolbar the "bookmark" button allows users to save links within the group. It allows users to enter a title and description. The web interface button allows users to only insert a link. The web interface also allows users to create a "Topic". For a "Topic" a user is required to enter a title and the body of the post. The interface also allows users to add a "Comment" on posted bookmarks and topics.
	REC 6 The ability to tag and rank search results	The user can rate "bookmarks", "snippets" or "annotations". Like and Tag features are not	Users can Tag the posts in folders with keywords. The user is also able to like posts and comments.	The user can "like" or "tag" links and topics but not comments. Rank feature not available

		available.	The rank feature is not available,	
	REC 7 The ability to structure and list stored information	This feature is not available. “Bookmark”, “query terms”, “snippets” and “annotations” are stored either by time, rate, username or title. Users can not manually re-arrange the bookmarks searches, snip or annotation.	This feature is supported through allowing users to “Create Folders” and store the links and posts within the folders. The user is allowed to “edit” the folders and “move” posts and links to other folders. Users can create unlimited numbers of folders to store information the User can re-arrange posts and links in a folder by dragging and dropping.	This feature is not available. “Bookmarks” and “Topics” are stored chronologically and can be filtered by type. Users can not manually re-arrange the bookmarks searches, snip or annotation.
	REC 8 A Cross-modal representation of stored structure	This feature is not available.	This feature is not available.	This feature is not available.

Awareness of IS process and workspace		This is available through notifications that appear in the sidebar. No visual or audio alerts are associated with IS process or workspace awareness.	This is available through a popup message that appears when a new post, link, or comment is added to a folder. The user can also view all recent updates through "recent activity region".	This is available through sending daily email alerts to team members about new links and topics in a shared group.
	REC 4 An integrated solution that allows user to communicate together	A chat and instant messaging tool is available in the sidebar. It provides audio alerts when a new message is received. The alert is disabled by default	Chat and instant messaging is available through TeamChat. Alerts when a new message is received is not available.	This feature is not available.
	REC3 Sharing current and previous search results page	Collaborators' searches appear in the history and notification regions in the sidebar and in the CSpace webpage. By clicking on each search term the user can view search results pages. User name and timing information are included with each search term	Previous search button is located next to the search engine dialogue box. Each search term is a hyperlink which directs to the search results pages. No additional details associated with search term	This feature is not available.

	REC10 Providing a cross-modal representation of collaborators' current IS activities.	Collaborators' searches appear in the notification region in the sidebar No cross-modal representation is available	This feature is not available.	This feature is not available.
	REC11 Providing a cross-modal representation of collaborators' past IS activities displayed chronologically.	In the history region previous IS process activity appears under the search tab It includes metadata such as name of team members and date. No cross-modal representation is available	Past search button next to the search engine dialogue box Each search term is a hyperlink which directs the user to the search results pages. No additional details associated with search term. No cross-modal representation is available.	This feature is not available.

	REC9 A cross-modal representation of changes that have happened in the shared workspace	Changes in workspace appear in the CSpace and also the notification region in the sidebar. However changes in the shared notes do not appear either in the notification region or in the CSpace	This includes: Recent activity and a temporary popup visual notification message appears on the updated folder; this also contains numbers of new post next to the folder name. In recent activity, updates are organized chronologically in the recent activity region. It includes collaborator name, type of item added, the timing and a URL to the update folder.	Summary of updates happens within a group via daily email Email notification on specific items (links or topic) When a user adds a comment, edited or deleted a specific item the collaborators get a notification if notification on items are enabled. Notifications on items are disabled by default

Table 7.2 Mapping the recommended features onto the components of the candidate CIS systems.

7.6 Accessibility Review

7.6.1 Method

The exercise described in this section aimed to identify accessibility problems in the candidate systems' interfaces in order to be able to select the most appropriate one for use in study 2. The aim was not only to evaluate whether the systems complied with accessibility standards, as often websites that are claim to meet accessibility standards may still have crucial or important tasks that are difficult or even impossible to perform by the target group of users. Therefore, we aim to examine the feasibility of completing the different tasks in the candidates' interfaces using screen readers. A number of studies follow a similar evaluation approach to the one adopted here. The approach is based on looking for scenarios that bring accessibility problems to light rather than examining pages for their compliance with web accessibility standards. Mankoff et al. (2005) asked a number of web-developers and VI users to perform tasks on a number of websites. By using a think-aloud protocol the participants highlighted accessibility issues they came across. Brajnik (2006) developed the barrier walkthrough evaluations framework that can be used to manually evaluate the accessibility of web-based interfaces for diverse groups of users. In his approach he suggested a heuristic walkthrough (Sears, 1997) method based on the concept of accessibility barriers. He defines accessibility barriers as "*any condition that makes it difficult to make progress or achieve an objective by a disabled person using the website through specified assistive technology*" (Brajnik, 2006). The method is an adaptation of the heuristic walkthrough (Sears, 1997) for usability investigations where the principles are replaced by barriers. The basic underlying idea is that, for testing and assessment purposes, it is better to start from known types of barriers rather than using general design guidelines. These barriers are derived from W3C guidelines and previous accessibility investigations (Brajnik, 2006). His approach comprised three stages: (1) defining the relevant goals and scenarios to be tested; (2) cross check the barriers with the selected pages or scenarios; (3) determining the severity of each barrier. The evaluation methodology conducted in this exercise is substantially based on Brajnik's (2006) barrier walkthrough study.

This exercise is not intended to perform a full accessibility evaluation of the systems. The VI user barriers list provided by Yesilada et al. (2009a) was used as an initial basis for the exercise. These barriers are compiled from different interpretations of WCAG 1.0 and 2.0. However in this exercise we identified barriers that were not initially listed. In the barrier walkthrough approach a set of webpages are usually identified for evaluation (Yesilada et al., 2009a). However in this exercise we defined a set of tasks to drive the evaluation process. The three main reasons we chose to base the check for barriers on tasks rather than webpages was: (1) Coagmento and Diigo involve the substantial use of toolbars, sidebars and menus in addition to webpages; (2) both Diigo and SearchTeam are single page applications where all interactions happen in one single webpage (Mikowski and Powell, 2013, p. 5); (3) the focus of the research is on the CCIS process, which is task oriented, and so it is more appropriate to adopt an approach which places emphasis on the performance of CCIS tasks. The criteria for choosing the set tasks to be performed is included in section 3.6.2.

7.6.2 Participants

When it comes to manually evaluating the accessibility of a webpage, there is very little in the literature about the selection of evaluators (Petrie and Kheir, 2007, Yesilada et al, 2009b). The level of expertise has been a topic of concern in these studies (Petrie and Kheir, 2007, Yesilada et al, 2009b). These papers include a discussion concerning the benefits of involving an accessibility expert over involving developers with none or very little screen reader experience. Since the aim of this assessment is not only to identify accessibility barriers but to also determine if a task can effectively be completed by the target user, we decided to involve VI users in the evaluation. Involving the target users in the accessibility evaluation process can have a positive effect, as they can identify usability problems in the tasks completed (Lang, 2003). Two experienced VI participants were engaged with the principle researcher in performing the assessment. The evaluation was conducted separately with each participant. Both participants had over 15 years of experience with JAWS as their primary screen reader, with some additional experience in Voiceover. One participant had some experience with the NVDA screen reader, while the other participant had only tried it a few times (as he stated). Both participants had taken part in study 1 [S1,VP] and [S2,VP]. In section 8.4.1 we discuss the reasons why we considered that the participation in this accessibility review was unlikely to affect their performance and user interaction results in study 2.

7.6.3 Access Tools, Web Browsers and Platforms Used

The approach was applied to three selected interfaces (Coagmento, SearchTeam and Diigo) using three different screen readers (JAWS, NVDA and Voiceover) on two platforms (Windows and iOS). According to WebAIM's (2014) survey of (1465) visually impaired online users, JAWS is the most common commercially used screen reader, preferred by 50.0% of users, followed by NVDA with 18.6 %. Voiceover was reported as the third most used with 10.3% of the surveyed sample using it. All of the (14) VI participants in study 1 consider JAWS as their primary screen reader; six of them had also used Voiceover and one of them had used NVDA. In relation to web browsers, IE was the most used browser in the WebAIM study with 51.5% of the surveyed sample using it as their primary browser. This is followed by Firefox with 24.2% using it as their primary browser, while 10% of those surveyed used Safari as their primary browser. In study 1 12 participants considered IE as their primary browser while two participants used Firefox. Even though the usage of Voiceover and Safari is comparatively small, there seemed to be a rise in the percentage of users employing them in 2014 according to WebAIM (2014). Therefore, they were included in this exercise.

7.6.4 Procedure

The procedure was explained to the participants before starting the exercise. The concept of barriers to accessibility was explained, and then the participants were told that they would be performing an accessibility assessment exercise on the three CIS systems. Since evaluator [S2, VP] has no significant experience with NVDA, he did not evaluate the interfaces using NVDA. Additionally, Coagmento has no IE plugin so it was only investigated in Firefox using the three screen readers. Table 7.3 shows various combinations of screen readers, web browsers and CIS systems covered by each evaluator.

	JAWS		**NVDA**		**Voiceover**	
	IE	**Firefox**	**IE**	**Firefox**	**Safari**	**Firefox**
Coagmento	Coagmento has no IE plugin	[S1,VP] [S2,VP]	Coagmento has no IE plugin	[S1,VP]	Coagmento has no Safari plugin	[S1,VP] [S2,VP]
SearchTeam	[S1,VP] [S2,VP]	[S1,VP] [S2,VP]	[S1,VP]	[S1,VP]	[S1,VP] [S2,VP]	[S1,VP] [S2,VP]
Diigo	[S1,VP] [S2,VP]	[S1,VP] [S2,VP]	[S1,VP]	[S1,VP]	[S1,VP] [S2,VP]	[S1,VP] [S2,VP]

Table 7.3 Screen readers, web browsers, and CIS systems that each evaluator covered in the accessibility review.

The principle researcher would ask the evaluators to perform each task and then they would be asked to report any related barriers encountered during the task. Additionally, they were observed by the principal researcher while performing the tasks. The evaluators were also allowed to freely discuss issues with the principal researcher as well as asking questions while carrying out the tasks. When a barrier from the potential barrier checklist was identified, the participant was required to state which barrier was found, which was then noted by the principal researcher. The participant was then prompted to perform the task again and follow a trial and error process until a workaround was found. In the case that no workaround was found after a few attempts, the principle researcher would mark the task as incomplete. The evaluator's comments on the reason[s] why they were unable to perform the task were noted.

If the issue hindering the participant from completing the task is not a listed barrier, the principle researcher and the participant discussed and agreed on how the issue should be documented, which was then noted by the principal researcher. For each task the principle researcher noted down all related details which may include types of barriers encountered, along with any further issues and ways to overcome the barrier (these details can be found in Appendix C.2).

7.6.5 Results

This section presents a discussion of the types of barriers found (also available in Appendix C.2) while performing the exercise on the three interfaces using JAWS, NVDA and Voiceover.

Inaccessible components

Inaccessible webpages or system components were the most prominent barriers encountered during the exercise. This barrier type stopped users from continuing the tasks numerous times. Using both Coagmento (in tasks A:3, B:7, B:8) and Diigo (in tasks A:5, B:10) the toolbar was inaccessible using default mode navigation in JAWS, NVDA and Voiceover. Both Coagmento (Figure 7.1, A) and Diigo (Figure 7.3, A) toolbars contain buttons that allow users to perform fundamental CIS processes such as storing retrieved information in the form of bookmarks and snippets in the shared workspace. Both systems provided no alternative ways of performing these CIS functions other than via the toolbar.

The evaluators (as shown in Appendix C.2) identified an alternative approach to accessing the buttons in toolbars using Optical Character Recognition[28] (OCR) in JAWS and object navigation in NVDA[29]. However these approaches are not straightforward and require a number of steps to be carefully conducted in order to complete the task.

System navigation issues

The Coagmento sidebar has no keyboard shortcuts to reach the different panels in the sidebar which are history, chat, notepad and notification. Additionally, heading navigation is not supported in the

[28] http://www.freedomscientific.com/downloads/jaws/JAWSWhatsNew
[29] http://www.nvaccess.org/files/nvda/documentation/userGuide.html#Objects

sidebar, thus users have to use serial navigation techniques in order to reach the sidebar panels. In fact participants using Voiceover with Firefox were not able to reach the Coagmento sidebar (Figure 7.1, B) (in tasks A:3, D:4, D:5, D:6). The Coagmento sidebar also contains a large number of functional images that have no or ambiguous descriptions and redundant links associated with them. These images are basically controls that allow the user to rank, sort and view saved bookmarks, snippets, and files as well as viewing previous searches. The evaluators attempted to label the graphics controls in the Coagmento sidebar, but the JAWS "label graphics" function did not work for this. The presentation of these functional images hindered the evaluators from efficiently using them in completing the tasks.

None of the interfaces examined provided keystrokes to initiate functions or to enable navigation to specific regions of the application. This made the process of navigation harder, particularly in the case of interfaces that relied heavily on images as buttons. Moreover, navigation by heading (using the H key) was not supported in Coagmento and had very limited support in the other two systems. In Coagmento VI users were limited to sequential navigation (using arrow keys) as the only option to reach a component in the toolbar, sidebar or CSpace webpage. In SearchTeam and Diigo, heading navigation was limited to search result navigation in SearchTeam and posts in both Diigo and SearchTeam. Reaching essential system features such as adding a topic or bookmark in Diigo, and navigating to the search tab, creating a folder or adding a post or a link in SearchTeam were not reachable via heading navigation.

Another navigation issue highlighted during the evaluation was the complete inability to reach some components even when using serial navigation. For example to perform task (D:1) (sending a chat message) in search team a VI user would need first to click on the team chat button (figure 7.2, C) to open the instant messaging modal dialogue box. However once the dialogue box is opened, a VI user is not able to reach the chat message edit box using serial navigation. The reason is that team chat opens in a form, not within the SearchTeam webpage context; above it as a modal dialogue form and the user can only reach the team chat using a mouse. To solve this issue the evaluator used the screen reader's built-in search function, searching for the term team chat. This action has the effect of moving the screen reader's focus to the team chat dialogue form, in which the user can then write and send a chat message.

Form navigation issues

A navigational issue encountered during the barrier walkthrough evaluation was a problem when navigating the SearchTeam add post form with JAWS. The normal JAWS behaviour when filling a form did not begin. VI Participants had to use cursor keys to navigate through the form controls instead of the usual TAB key; when the tab function does work properly, it automatically switches to the next control on the form, saving navigation time. In this case However the use of the TAB key in the add post form would not allow proper navigation of the form, and often resulted in moving the screen reader 's focus to outside of the form. A similar issue occurred when adding a bookmark in Diigo (in task B:10), as navigation using the TAB key did not allow the user to access the "more options" controls. Both VI evaluators recognized the issue and used the arrow keys to navigate through the form controls successfully.

Lack of alternative text

The failure to provide a text alternative for non-text content was another very common barrier encountered across all three interfaces. When the VI user navigated to non-text objects, they were not able to know the functionality of the object. This barrier can clearly significantly affect the use of the object, and can result in failure to complete the task. In Coagmento, the VI evaluators spent time looking for the edit field in the shared notepad region (in task B:9), as the edit field has not got a label that describes its purpose. Thus VI users were uncertain whether they were entering text in the correct edit field. A similar scenario happened in SearchTeam (in task B:4) when a user tried to add a post. The form had two edit fields that had no textual descriptions. Using Diigo (in task C:3), VI users were unable to locate the "search within the group" edit field, and so were unable to complete the task.

Moreover, a number of barriers were encountered with other webpage objects with no alternative text description, specifically with drop-down menus and images. In Coagmento the "Choose a Project" drop-down menu object has no label or description (in task A:4) so the user was not able to reach it.

The Bookmarks, searches, snippets and searches tabs in Coagmento contain many functional image buttons with no alternative or equivalent text, while some have ambiguous texts that do not provide any descriptions of the image button's functionality.

Mismatches between visual layout and audio rendering

There were instances recorded of mismatches between the visual layout of interfaces compared to how they were rendered in screen reader speech. In Coagmento the information within the "snippets", "search", "bookmark", and "file" tabs are arranged in a tabular layout. The tabular layout contains cells with many images that have ambiguous descriptions and redundant links associated with them. In (task C:5), VI users are required to read each one serially. With each selection, users must start from the top of the next table and read until they either reach the bottom of the table or find a desired link. While visually it looks like an organized set of records, navigating the structure using a screen reader was time consuming and confusing. Both evaluators expressed frustration in attempting to access the information in the structure.

Lack of alternative keyboard commands

Barriers related to the lack of keyboard commands as an alternative to mouse interaction were found in all three interfaces. However this type of barrier was more prominent when using both Coagmento and Diigo. In order to login to both interfaces (as required in tasks A:3, A:5) and store retrieved webpages (in tasks B:7, B:8, B:10) the user is required to navigate to the toolbar. Navigation of the toolbar using the keyboard was not possible via the normal navigation mode. As discussed earlier, the user is required to use OCR in JAWS or object navigation in NVDA to be able to navigate the toolbar. Both approaches are not straightforward and require several steps to reach one button.

Another barrier was related to mouse-over actions, where a menu appears once the mouse is over an object. In Diigo, this barrier was encountered in two tasks. In task (B:7), the user was unable to share a bookmark with the group as the menu did not appear when the focus was on the checkbox object. This issue was encountered again when the user attempted to set an alert on a post (in task D:7), a mouse-over action happens when the mouse is over the "more options" link, that causes a menu to appear. Only JAWS and Voiceover had an alternative keyboard command for mouse-over actions. NVDA requires the user to use an alternative navigation mode (object navigation) to reach the mouse-over object and perform the task. Even though these keyboard commands (in the case of JAWS and Voiceover) and techniques (in the case of NVDA) were tried during the evaluation, none of the screen readers were able to identify the mouse-over object in Diigo.

Since there were no keyboard alternatives for this action, the user was not able to complete this task. In contrast to this, the previous search mouse-over object in SearchTeam was fairly accessible using the JAWS alternative keyboard command. After a few attempts, task (D:3) was completed successfully by evaluator [S2,VP] who used the JAWS keyboard alternative to access the mouse-over object.

Another rich internet application-related barrier encountered during this exercise was drag and drop functionality. In SearchTeam the user is able to rearrange posts by simply dragging and dropping posts in the required place. This functionality does not have a keyboard alternative, and since SearchTeam does not support WAI-ARIA use of tags, there was no alternative approach to perform the task (task B:5).

Lack of feedback

All three interfaces do not provide feedback when a message is saved. Sighted users can visually find the post added; However VI users need to navigate to the shared workplace and go through the stored information to verify a message has been stored, a much slower process. Another feedback-related issue occurred in both SearchTeam and Diigo. These systems do not provide VI users with a notification of missing information when filling forms. When a field is missed and a user clicks the save button in SearchTeam or the post button in Diigo, a VI user does not get very clear feedback about missing information. Both interfaces leave the form open in order to let the user know that the information is not saved. SearchTeam adds a message in red under the missing form field, and the only way for a VI user to find this message is to navigate through the form until they find the message.

Dynamic changes not rendered

Incidents were recorded when dynamic changes were not rendered to users by screen readers. When a post is added to a folder by team members in SearchTeam, a popup message appears above the folder informing the user about the updates. The popup message stays for one minute then disappears. All three screen readers used in the exercise did not render this notification. In Coagmento, updates in the notification region in the sidebar and instant search results on the same page were not rendered. Receipt of new chat messages is another change that is not rendered by screen readers in SearchTeam. Unless the user happens to navigate to these areas of the screen and view the changes, VI users would not be aware of changes made.

7.7 Suitability of the Evaluated Interfaces

The previous two exercises were conducted in an attempt to guide us in choosing the most eligible interface that satisfied the design recommendations for CIS system features identified from our baseline study; they also needed adequate levels of accessibility. According to the functionality review in section 7.5 SearchTeam is the only interface that has a collaborative search engine embedded into it. Thus it provides a fully integrated solution that includes a search engine, shared workspace and communication tool (REC4).

All three interfaces provide multiple ways to manage retrieved information. However SearchTeam is the only tool that allows users to structure retrieved information by creating folders (REC7). The instant messaging feature is only available online in Coagmento and SearchTeam, as Diigo is not a CIS tool but a tool to share bookmarks with users. Moreover, Coagmento is the only tool that provides an audio alert when a new message is received

Both Coagmento and SearchTeam provide information about the IS process (REC3 and REC11) such as the search terms entered and search results page. However Coagmento provides additional information, such as the timing and the name of the user. All three interfaces provide information about the updates that have occurred in the shared workspace (REC9). As seen in table 7.2, each tool presents this information differently. SearchTeam provides updates about the IS process and shared workspace in two different places, while Coagmento combines them in the same place. Both the Coagmento and SearchTeam interfaces employ dedicated views to provide awareness information to users, while Diigo sends users a daily email notification.

there were substantial differences in levels of accessibility and barriers recorded across the different interfaces. Coagmento and Diigo have major navigation issues in regards to navigating to essential features in the toolbar that hindered evaluators from performing many key CIS tasks, as reported in section 7.6.5. Additionally, the majority of regions and tabs in Coagmento seem cluttered, with functional images associated with ambiguous or missing text descriptions.

We deduced from the exercise that SearchTeam was by far the most suitable tool both in terms of its CIS functionality and the accessibility of its features. Firstly, it provides a fully integrated single page web application (REC4). Unlike Coagmento and Diigo where the user is required to toggle between the webpage, toolbar and also sidebar (in the case of Coagmento). The overhead of switching from one application to another was an issue that VI participants encountered, as reported in study 1. The issues VI evaluators found in accessing toolbars lowered the chances of considering both Coagmento and Diigo. Coagmento and Diigo do not allow users to structure retrieved information, while SearchTeam provides an accessible way of storing retrieved information in a structured manner as users create folders (REC7). Within SearchTeam, most functionality was fairly accessible and tasks were conducted relatively easily, with the exceptions of some issues with the lack of alternative text in some edit fields and a few navigational issues. From the accessibility assessment conducted, SearchTeam worked relatively well with all three screen readers across all platforms.

7.8 SearchTeam Interface Features and Functionality

SearchTeam is a single page application where all interactional components are located in one webpage, as seen in Figure 7.2. As described in the previous chapter, SearchTeam is an interface that is specially designed to support the CIS process. It consists of the four major interactional components that support this process: the search engine, user-created folders, team chat and view of recent activity region.

7.8.1 Search engine

SearchTeam has an embedded search engine (Figure 7.2, A). Next to each search result there are save and hide buttons. These allow the user to save search results in one of the folders that the user has created. Users can also hide some search results so that one can more effectively sort through the unhidden results.

7.8.2 Shared Workspace

The user is able to create folders and work with teammates to effectively organize the retrieved information (Figure 7.2, B). Once in a folder the user can manually add a link, add a post, or can add a file from different media. Saved items from the search results page using the "save link" feature will appear in the folder they are saved in. The user has the ability to move posts and saved links across folders, delete or rearrange them. With folders users are able to "like" a post or a comment by pressing on the 'like' link. SearchTeam also allows users to add tags and comments on stored posts and links. Multiple tags and comments can be added to a single post. The system displays the usernames of the collaborators who performed the action.

7.8.3 Communication and Awareness

SearchTeam provides a number of features that facilitate communication and awareness during CIS activities. It provides team chat which is an instant messaging service that allows users to communicate with team members that are online. To facilitate awareness, SearchTeam allows users to view previous searches performed by team members through a "past search" mouse-over dropdown list located next to the search engine button. It also dedicates a whole region that records the "recent activities" of team members (Figure 7.2, D). All updates that occur within folders are reported chronologically in this “recent activities” region. Additionally, a pop-up message appears just above the tab of the folder being updated with details of recent updates.

7.9 Recommended Enhancements to SearchTeam

In this section we discuss the recommended enhancements we made to SearchTeam. The aim of the enhancements was to firstly improve the level to which SearchTeam supports the design recommendations for CIS system features made in section 6.3, and secondly to improve the user experience. Table 7.4 provides a summary of the recommended enhancements and their feasibility. It was crucial to us to determine the feasibility of each recommended enhancement, as the ability to improve its accessibility by modifying the underlying source code was not available, as there was no access to the source code of the application. We present the implemented enhancements in section 7.10.

	Highlighted issues	Description	Recommended solutions	Feasibility of the solution
Supporting Awareness of Dynamic Changes	Dynamic updates	New Post and new Chat message updates	JAWS Script to monitor pages changed and produce audio alerts when changes happen	Feasible
			Marking the folder area and Team Chat as WAI-ARI Live Region[30]. That is for the screen reader to be able to render the new changes.	It is not feasible as it required modifications to the source code.
	Forms Feedback	Error messages alert in new post	JAWS Script to monitor pages changed and produce alerts when changes happen	It is not feasible as the new post is a modal dialogue form window that opens over the webpage. It was not possible to develop a JAWS script that monitored dynamic changes in the modal dialogue form window.
			Marking the folder area and Team Chat as ARIA-Live Region. That is for screen readers to be able to render the new changes.	It is not feasible as it requires modifications to the source code.
Supporting Users' Navigation	Navigating to commonly accessed areas	Reaching the four major components of Search Team.	JAWS settings (JAWS PlaceMarkers[31]) allows quick navigation to marked up areas within a webpage	Feasible.
			Using WAI-ARIA landmarks[32] to identify regions of a page	It is not feasible as it requires modification to the source code.
	Lack of explicit	- Form navigation issues	Changes in JAWS voice to identify form controls to	Through JAWS speech sound

[30] http://www.w3.org/TR/wai-aria/states_and_properties
[31] http://www.freedomscientific.com/Training/Surfs-Up/placemarkers.htm
[32] http://www.w3.org/WAI/GL/wiki/Using_ARIA_landmarks_to_identify_regions_of_a_page

	labelling	- Lack of alternative text - Heading navigation	solve navigation issues.	schemes[33]
			Label the forms and form controls appropriately in the code. Add a descriptive ALT text for images. Clearly identifying the page heading in the HTML code.	It is not feasible as it requires modification to the source code.
Supporting cross-modal interaction	Keystrokes to initiate functionalities	Open chat messages, send chat messages, create folder, add a post and Search	Open chat messages: JAWS command that allows VI users to view the chat dialogue without having to navigate to the team chat modal dialogue form	Feasible by creating a JAWS script the store all chat messages in the JAWS virtual viewer.
			Send chat messages, create folder, Add a post and Search	This is not feasible as it requires modification to the source code.
	Lack of alternative keyboard commands	Arranging posts using the drag and drop feature in folders	WAI-ARIA introduces drag and drop properties [34]that help web application authors assign drag and drop operations to an object. The object is identified by the screen reader and the user can perform drag and drop operations using the keyboard.	This is not feasible as it requires modification to the source code.

Table 7.4 A summary of the feasibility of the recommended enhancements.

[33] http://www.freedomscientific.com/Training/Surfs-Up/Speech_Sounds_Schemes.htm
[34] http://www.w3.org/WAI/PF/aria-practices/

7.10 Enhancements made to SearchTeam

We chose to implement the improvements for users employing the JAWS Screen reader and IE, as they are currently the most popular combination of applications for accessing web-based systems amongst the target population (Brown et al., 2012; WebAIM, 2014). The enhancements were implemented using JAWS scripts and JAWS settings. We designed the functionality of the JAWS scripts and delegated the task of their implementation to Brian Hartgen [35], a consultant JAWS programmer. After every iteration of development, we tested each functionality separately. We then adjusted the JAWS settings according to the recommended enhancements. In this section we discuss the enhancements we made to SearchTeam, detailing the design and implementation of each enhancement.

7.10.1 Supporting Awareness of Dynamic Changes

As reported in section 7.6.5 dynamic changes such as new popup messages concerning folder notifications and new chat messages were not rendered by the screen readers tested. Therefore we provided a sound alert in an attempt to satisfy REC8. This is done using a JAWS script.

New post alert

For new post alerts we used earcons (Blattner et al., 1989), non-speech sounds often used to render system messages. Despite the rather limited research on their applicability to the web, studies which examined their use in web interaction have revealed their effectiveness in improving user experience when used in combination with speech (Petrucci et al. 2000, Susini et al., 2002). We therefore decided to employ earcons and speech for the alert delivered to users. The earcon used is followed by a message that reads the names of the folders that have been updated and the number of new posts in each updated folder. The user can also employ the JAWS script keyboard shortcut F12 to repeat the notification message.

[35] http://www.hartgen.org/

New chat message alert

We developed a JAWS Script to notify a VI user of the arrival of a new chat message. The alert comprises an earcon followed by a speech alert to notify the user of the arrival of a new chat message. The earcon used for a new chat message is the same earcon used for the new post alert but played in reverse to enable the user to distinguish between both alerts.

7.10.2 Supporting Users' Navigation

In an attempt to improve VI users' navigation experience using SearchTeam, we introduced a number of enhancements. The enhancements introduced are described below:

JAWS PlaceMarkers

The JAWS screen reader provides a PlaceMarkers feature that allows fast navigation to commonly accessed areas within an HTML document. Using JAWS settings, we assigned PlaceMarkers for each of the four major components of the interface identified in figure 7.1, to help users navigate quickly to the major components of the ACSZ interface.

Audible chat messages keyboard command (ALT+CTRL+V)

Navigation to the team chat modal dialogue form window was not straightforward as reported in section 7.6.5. To improve the user experience, we introduced a JAWS command using a JAWS script that allows VI users to view the chat dialogue without having to navigate to the team chat modal dialogue form. The command saves all messages into the JAWS Virtual viewer. To access all the chat messages, the user can use the ALT+CTRL+V keyboard shortcut which will bring all the chat messages into the JAWS Virtual Viewer for easier inspection.

Change in JAWS voice to indicate form controls

To deal with the lack of alternative text in forms edit fields and buttons, and because we did not have access to the application's source code, we employed JAWS speech and sound schemes to help users easily identify components of the interface easily. A female voice was assigned to buttons and a male voice (with a low pitch) was assigned to edit boxes.

Reaching the team chat window

The above enhancements were introduced using either JAWS settings or JAWS scripting. However navigating to the team chat modal dialogue form, which was identified as a barrier in section 7.6.5, was addressed differently, because we did not have access to the application code of ACSZ to solve this issue. We introduced navigation tips in the training, advising participants that to reach the team chat modal dialogue form, they would need to perform two steps:

1) To open the team chat dialogue form window by simply navigating to the button in the page and pressing enter. Once the window is open, it will remain open throughout the session providing the user does not exit IE.

2) To reach the team chat dialogue window and send a message while the chat message dialogue window is open, use the JAWS built-in search to search for the term team chat.

7.11 Chapter Summary

This chapter described the analytical approach taken to select the most eligible system to be used in study 2 (described in the following chapters). The analytical approach consists of two parts; the first part, discussed in section 7.5, consisted of examining the features and functionality of the potential CIS interfaces; the second part, presented in 7.6; involved assessing their accessibility. This approach resulted in the choice of the SearchTeam system which is introduced in section 7.8. The choice was ultimately made relatively straightforward since SearchTeam was by some way the most appropriate system to use according to both sets of criteria (support for CIS functionality and accessibility). Finally section 7.10 describes the enhancements that were then made to further improve the support for the design recommendations of CCIS system features of section 6.3 and to improve the user experience. In the following chapter we describe an observational study of VI and sighted users' CCIS behaviour using the extended SearchTeam interface which we refer to as ACSZ.

Chapter 8 Study 2: CCIS using ACSZ interface- Collaborative Interaction Results

8.1 Introduction

In this chapter we describe an evaluation study that explores CCIS behaviour between VI and sighted participants using the CIS extended ACSZ tool in co-located and distributed settings. The overall aim is to understand behaviour, the process and challenges that arise when a mainstream CIS tool with extensions to support screen readers' accessibility is introduced. This chapter starts by presenting the motivations behind this study, followed by a detailed discussion of the research questions in section 8.3. Section 8.4 describes the study design and section 8.5 presents the first part of the findings that focus on the collaborative aspects of the evaluation. Chapter 9 then presents the findings related to the individual aspects of the process and discusses participant interactions with the interface.

8.2 Motivation and Contributions

Prior to choosing the tool and building a JAWS script that supports its use with screen readers, we conducted an exploratory study to investigate the CCIS process described in chapter 5 and 6, the challenges that occur, and the affect the process has on the stages of information seeking. The exploratory study gave rise to a set of design recommendations to improve the accessibility of the CCIS process, described in section 6.3. Those design suggestions were considered within the context of features available in mainstream CIS systems. We then performed an evaluation to identify the level of accessibility of existing CIS systems, and whether any one of them would be suitable for use in a CCIS study, described in section 7.6. This evaluation resulted in our identifying one system that could be made sufficiently accessible to use in a study of CCIS. Every effort was made to reduce web accessibility problems and their impact on the results of study 2. The focus of this thesis is on CCIS, not on web accessibility, but the study of CCIS cannot be entirely separated from issues of web accessibility. Where it was technically possible for us to do so we introduced extensions and JAWS-related features to improve the accessibility of the SearchTeam system. We did not have access to the internal coding of SearchTeam so we were unable to introduce automatic means of removing these problems, such as in the forms for making posts. The relatively experienced profiles of our VI users, and the fact the observer was on hand to advise of these difficulties and how to get around them, meant that we were able to minimise their impact on the overall results of the study.

We conducted the study to examine the CCIS process in the presence of an interface that supports it. The contribution of this study is to provide an understanding of users' interactions with the system and with each other. It provides insights into information seeking behaviour when using the extended CIS tool. It explores strategies and the ways in which labour is divided between collaborators. It investigates the group and workplace awareness information exchanged between users in the presence of a tool that directly supports this process in an integrated way, something that was not present in the first observational study. Finally we highlight the usability and accessibility issues encountered. To the best of our knowledge this is the first study of that examines the CCIS process using a system specifically tailored to support it. Furthermore we are not aware of any study in the field of CIS that evaluates the process from both an individual and collaborative perspective. The ultimate goal of this study is to inform the design of a tool that support CCIS.

8.3 Research Questions

To be able to support the process of CCIS we aim to provide an understanding about what happens to cross-modal collaborative interaction when a tool is introduced specifically to support it. Given the complexity of the process, as described in section 2.7, which includes collaborative interaction as well as user interaction with the interface, evaluating the CIS process could be looked at from various angles, including the collaborators, the user and the system. Thus we defined a set of research questions in more than one dimension. This study will look at the process from two perspectives: user interaction and collaboration. These aspects are two of the dimensions introduced by Shah (2014). The system-focused dimension, the third dimension introduced by Shah (2014), was excluded for two reasons. Firstly ACSZ is an existing commercial interface as described in section 7.4, so we had no access to data logs for us to examine IR concepts such as relevancy or precision. Secondly and more importantly evaluating the technical efficiency of a CIS engine is not within the scope or focus of this thesis. The following subsections respectively discuss the collaboration and user dimensions along with research questions we aim to answer in relation to each dimension.

8.3.1 The Collaborative Interaction

This study refers to the team interaction as collaboration. It includes the collaborators' performance, their interaction to facilitate group and workplace awareness, and the ways in which they divide and manage labour between them. The measures of CIS performance are likely to vary depending on both the aims of the searchers and, to some degree, with the platform that they are using. In studies involving CIS activity performance can be looked at from a variety of aspects. Studies that measure search engine performance employ traditional and non-traditional IR evaluation metrics such as (Pickens et al, 2008). Studies that focus on user performance are mainly dependent on the usability and efficacy of the designed interface, such as (Morris and Horvitz, 2007a). These studies use log data, and answers to questionnaires and interviews to assess users' performance. The amount of information retrieved and stored was also considered as an indication of user performance in CIS studies (Halvey et al., 2010). Some early studies treated the performance of a group as the summation of the performances of the individuals in the group (Baeza-Yates and Pino, 1997), which tended to ignore the team aspect and interaction between collaborators. Therefore it was clear to us from the start that one single measure is not sufficient for evaluating collaborators' task performance. In this study we based the task performance evaluation on the two following factors:

1. Tasks completed and tasks that overlapped

RQ1: Is the amount of subtasks completed more using the ACSZ system (study 2) than using separate applications (study 1)?

The tasks used in this study are equal in structure and the amount of information to be retrieved and synthesised as the tasks used in study 1. The tasks' descriptions and structure and the criteria under which the tasks were designed is described in section 3.6.1. The team is required to search for 13 pieces of information. We observe the amount of the task completed by each team and by each collaborator, the amount of the task performed collaboratively and the amount of task overlap. Task overlap refers to the situation where one subtask is mistakenly done by both collaborators. We compare the results of this study to the result of study 1 to identify the impact of the ACSZ interface on participants' task completion.

2. User satisfaction rates from the post-study questionnaire

RQ2*:* Are the participants more satisfied with their performance in the search tasks using ACSZ (study 2) than using software tools which they routinely use in everyday tasks (study 1)?

As with study one we interviewed the participants after each task. We asked them to rate their performance and communication levels. This is to have an insight about their level of satisfaction with using the interface, and if they think it enhanced their level of performance. We also asked about how well they think they communicated with each other during the task. To answer this question we relied solely on the post-study interviews.

RQ3: Did participants divide the labour differently when using ACSZ (study 2) than using software tools which they routinely use in everyday tasks (study 1) and what was the nature of any such differences?

This question examined the division of labour strategies that emerged in the presence of the ACSZ system. It looks into ways participants divided the labour between them and the patterns of behaviour that arose. The results of study one showed that division of labour was quite different in each setting. In the co-located setting pairs tended to employ a 'divide and conquer' strategy (Morris, 2008) to divide the labour but in the distributed setting the collaborators used a 'brute force' strategy. Additionally decisions regarding the division of labour were influenced by the previous experience of the VI user concerning accessibility levels of typical web sites.

For instance they would delegate tasks that involved making bookings to their sighted partner to avoid the likelihood of them wasting time attempting to complete inaccessible web forms.

RQ 4: What is the impact of the awareness mechanism made available by ACSZ on the information exchanged by users to provide awareness information to their partners?

ACSZ provides a shared workspace as well as a number of features that provide group and workspace awareness information. The results in study 1 showed that in the absence of a shared place to store information with no cross-modal interface, participants exchanged information with their partner in an attempt to improve group awareness. RQ4 investigates whether the group and workplace awareness information available using the interface had an impact on the amount and type of information explicitly exchanged between partners.

RQ5: How do the participants make use of information they receive? And does it have an effect on the amount of the task completed (Participants' tasks performance) as in study 1?

In study 1 it was observed that users make use of received information differently in each condition. Additionally, it was noted that this had an effect on collaborators' task performance. This agrees with(Shah, 2012) which shows that providing the appropriate awareness information can lead participants to reduce their efforts in communicating awareness information and hence improve their performance. RQ4 looks into the uses participants made of the information received and examines whether these had any impact on task performance.

8.3.2 User Interaction

This study refers to user interaction which includes the individual IS process, user interaction with the interface, and VI participants' interactions with accessibility enhancements made to the interface.

RQ 6: What are the effects of the use of ACSZ on information seeking behaviour?

RQ 7: How do the participants organize and managed retrieved search results in the presence of a shared workspace?

Studies have revealed that IS stages are typically completed individually most of the time, and collaboration rarely (Shah and Marchionini, 2010; Shah and González-Ibáñez, 2010). Study 1 demonstrates that, most of the time, the stages of IS were performed individually. In RQ6 we look into the stages of IS when using the ACSZ tool, we explore the amount of collaboration that happens in each stage and the effect of the tool on the stages of IS. As described in section 7.8.2, the tool provides the user with multiple features to structure and store information in the shared workplace. The aim of RQ7 is to explore strategies and ways in which participants have stored and structured retrieved information.

RQ8: Are the participants satisfied with the overall user experience? And

RQ9: How do they interact with ACSZ components and features?

RQ10: How do the VI users interact with the awareness and navigation enhancements made?
RQ9 investigates specific features of the tool that are used, and whether these appear to either improve the usability of the system and/or improve the performance of tasks. We identify ones that are not used or that cause confusion/reduce usability. RQ10 looks into the frequency of use of the main features including the JAWS scripted features, the accessibility issues encountered and the ease of use and satisfaction levels.

In order for us to be able to explore what happens when a dedicated CIS interface is introduced to the process, we make comparisons with findings from Chapters 5 and 6 to examine how the introduction of this interface impacted the CIS process, specifically in relation to the collaborative process. The same issues are discussed across the two studies, including participants' performance, awareness and division of labour, and the stages of the IS process. The results of study 1 from chapter 5 and 6 are considered as a baseline study, and direct comparisons are made where possible.

8.4. Study Design

The evaluation started by administering a pre-study questionnaire to collect information about the participants. Since the participants had been involved in study 1, demographic data were not collected. However they were asked about their information seeking habits and VI users were asked about their use of assistive technology. This was followed by a structured observational study that involved pairs of participants conducting two separate search tasks. One task was performed in a co-located setting and the other task was performed in a distributed setting. Each participant was interviewed after each task. The study design introduced in this section is fairly similar to the study design in study 1 section 5.4 as discussed in the previous section, because we wish to make comparisons between the two studies to some degree. Therefore, the procedure in this study is structured in a similar way as study 1.

8.4.1 Participants

For this study the same 14 sighted and VI pairs that participated in study 1 were recruited; they were contacted via mailing lists. They were financially compensated for participating at the rate of seven pounds per hour. Demographic data can be found in section 5.4.1. Participants [S1, VP] and [S2, VP] both participated in the accessibility review discussed in section 7.6. Their participation in the accessibility review was very unlikely to influence their performance in study 2 for two reasons; firstly, it was quite a long period of time (8 months) between the accessibility review and study 2. Secondly the enhancements made to the interface, when presented as an integrated whole, provided a rather different user experience than that during the accessibility review, which focused on a series of specific barriers and specific artefacts in each interface in turn.

8.4.2 Set-Up

As in the previous exploratory study, the intention of this study is to observe participants in a real world environment. The studies were done either in the VI participants workplace or in a meeting room at the university. In the distributed condition participants were seated in separate locations. The sessions were all videotaped upon approval of the participants and both participants' screens were captured using screen recording software. Additionally observer notes were taken during the sessions.

8.4.3 Task

As discussed in section 3.6.1 in order for us to compare some of the results of this study with the results of study 1 we chose to use the same task structure as study 1, albeit with slight modifications to the context of the task. The modifications include the cities to be visited in each task and the activities to be organized. However the number of cities and activities to be visited remained unchanged. In the co-located condition in this study, participants were asked to work collaboratively to organize a business trip to the Middle East, and for the distributed task they were asked to plan a business trip to Italy. Each task involves visiting three cities; the participants are required to arrange travel and accommodation in each city. They were also given dates of engagements in these cities. The number of activities and engagements were equal in both tasks. They were asked to collect relevant information that would help them in making the actual booking later in time. The tasks used in study 2 can be found in appendix D.4.

8.4.4 Procedure

Each session included three main parts as follows:

1. Pre-study questionnaire: Participants were asked to fill a pre-study questionnaire to obtain information about the type of assistive technology they use, their familiarity with search engines and how long they have been working together. The pre-study questionnaire can be found in appendix B.2.

2. The training: After a brief introduction to the purpose of the interface, its main parts, and the purpose of this study, participants were then provided with a 10 minutes demonstration of the system. The demonstration included the main features of the interface, ways to perform different actions in the interface and, in the case of VI users, the main features that the JAWS Script provides. Following the demonstration each participant was given a brief training manual (which can be found in Appendix D.2 and D.3). The training manual contained instructions on how to perform the main actions in the interface which included: using the search engine, creating a folder, posting,

deleting and editing posts and comments, using the team chat function and viewing the recent activity region. For VI participants the training manual also described the functionality of the JAWS Scripts and the use of the defined JAWS PlaceMarkers; section 8.4.5 explains the training process in detail.

3. The collaborative search task: The pairs were then asked to start performing a CIS task, using the CIS tool. We counterbalanced the order of the tasks across the pairs to minimize the influence that task order might have on the collected data. The users were stopped 35 minutes in from starting the task. Users were purposely not told that they had 35 minutes to perform the task so as to not impose a time factor on the activity. However as they had taken part in study 1, they probably had some idea of how long it was likely to take.

4. The post-study questionnaire and interview: Following the sessions a post-study questionnaire was administered that measured participant satisfaction regarding the usability and accessibility of the interface. This was then followed by a brief semi-structured interview with each pair. The interview helped in discussing usability, accessibility issues and challenges in more detail. It also allowed us to identify the features that the participants felt were most and least useful. Participants were also asked about other challenges they came across when they perform similar activities outside of the present study. Finally suggestions and possibilities to improve the CIS interface were discussed. The post-study questionnaire and primary questions asked in the semi-structured interviews can be found in appendices D. 5 and D.6.

8.4.5 Training

Due to the time constraints training was structured so participants had an overview of the interface; it then introduced features specifically related to CIS. The training procedure consisted of the following stages:

1. Demonstration of the different components: in this stage the interface and its different components were introduced to the participants, and a demonstration was provided of ways to access each component.

2. Introduction of the main features: Participants were asked to perform the major tasks that they would need to perform during the session. These were: creating a folder, using the search engine, saving a search result, adding a post, sending a chat message and checking the recent activity region. Participants were given six training tasks and each task required participants to try one of the features; they were then asked to rate the ease of use (1 being very easy and 10 being extremely hard). Appendix D includes the training documentations.

3. Introduction of the accessibility enhancements: VI users were introduced to the place markers created to make navigation within the webpage easier. JAWS script features and sound alerts were also demonstrated to the VI users. VI participants were also asked to rate the accessibility enhancements.

Participants expressed their comfort with using the interface. The majority of training tasks were easy for both groups of participants. Looking at the ratings of the training tasks and their verbal feedback, the hardest task to perform according to the VI participants was adding a new post. Participants rated it at an average of 4.85 out of 10 (SD= 2.8). The reason for rating it as the hardest task according to VI participants' feedback was due to the fact that they encountered the 'add a post' navigation issue described in section 7.6.5 of the accessibility review. This happens when the JAWS screen reader enters the add post form, as it does nots switch into forms mode automatically. Thus the user is not able to use the TAB key to move from one control to another. This caused some confusion for VI users, but the fact we had identified the problem during the accessibility evaluation enabled us to explain the issue and point to work around employing cursor navigation.

Another reason for rating the edit post dialogue as the hardest task is that edit boxes in the form are not labelled, which makes it hard for the VI participants to differentiate between the title edit box and the body edit box. This is also identified in the accessibility review (section 7.6.5), thus we were aware of this issue and we advised VI participants beforehand. The hardest feature according to sighted users is receiving a chat message. They rated this at an average of 1.71 (SD= 1.48). Two participants reported this as hard because it does not give an alert when a new message has been received.

In terms of time needed for training VI participants spent an average of 25:00 minutes with a standard deviation of 9:19 minutes; sighted participants spent an average of 13:35 minutes with a standard deviation of 3:62 minutes. VI participants required a longer training time because of the additional JAWS-specific features.

8.4.6 Data Collection and Analysis

During the study the main source of data was the video recordings of the interactions between partners, and the screen recordings of interactions with the interface. All recordings were transcribed and analysed to identify emerging patterns of behaviour as described in section 3.8.1. The study concluded with a post-study satisfaction questionnaire to measure the ease of use, which is contained in appendix D.5. The design of the questionnaire was influenced by the original Computer System Usability Questionnaire (Lewis, 1995). The questions were modified to be appropriate for the functionality of the ACSZ interface and the cross-modal context of use. Responses to these questions provided information on the perceived ease of use and levels of satisfaction with the tasks. This was followed by a brief semi-structured interview which was conducted individually with each participant to complement the data collected during the study. The aim of conducting the interview after the observational study was to allow us to discuss in detail the issues that arose during the interaction, and to collect views about ways to better support this sort of collaborative activity.

8.4.7 Limitations

One of the most important limitations of this study is the fact that participants were not familiar with the interface. The ACSZ interface is different from the simple search engine participants use for their search activities; they had to learn how to use it. Although the features are quite straightforward to use, the process of becoming quickly familiar with an interface using a screen reader is inherently more difficult. Compared with the visual interface, screen reader users are not presented with an ongoing display of the current screen; instead they are presented with a temporary rendition of the latest part of the screen that has the focus.

Furthermore this interface was not initially built to be accessible. While we were able to add features to improve access through JAWS scripting and JAWS settings as described in section 7.10, we were not able to alter parts of the existing interface, notably the inaccessible form mentioned above, as this had not been designed with accessibility in mind. Though these caused a few problems they were a relatively minor issues given the overall scope of the tasks being performed by participants.

8.5 Findings and Analysis

This section presents findings from the user observational study focusing on the team collaboration. The section starts with discussing the overall process observed in section 8.5.1, followed by detailed descriptions of task completion by each team member in section 8.5.2. Section 8.5.3 then presents results of participants' satisfaction levels in terms of their team performance and communication levels. Section 8.5.4 looks into the strategies employed for dividing labour, and sections 8.5.5 and 8.5.6 present discussions of group and workplace awareness information exchanged, by exploring the dialogue between the pairs. These findings are concluded with a discussion of observations relating to specific team's CIS behaviour.

8.5.1 The CIS Process

The process can be described as a series of stages that iterate throughout the session. The stages are slightly different in the co-located setting than in the distributed setting. The description of stages that occurred in this study is similar to the description of the stages that occurred in study 1. The description can be found in section 5.5.1. However the pattern of occurrences of the stages differed in study 2.

In the co-located setting stage 1 in study 2 involved agreeing on the way the information retrieved is organized. The participants usually discussed the number of folders to create and the names of folders and features to be used when storing information. Unlike the discussion of the division of labour about the search task, the discussion of how to organise the retrieved information was not present in all studies. It was more apparent in the co-located setting (the number of occurrences will be discussed in section 8.5.5). After completing stage 2 it was observed that in some stages participants would check their partner's posts. In stage 3 users generally discussed the tasks and in some cases reconsidered the division of labour in the remaining sub-tasks. For instance in one study the VI participant encountered accessibility issues which made him delegate the sub-task to his sighted partner. Stages 2 and 3 were then repeated until the task was completed.

In all distributed tasks a common pattern of behaviour was observed which comprised three stages somewhat similar to those observed in the co-located condition. However there was very little evidence that participants discussed division of labour later in the process (stage 3). Division of labour was discussed in five out of the 14 studies. It was observed, However that if one participant completed all the assigned task, they would check the posts and/or folder[s] created by the other participant in order for them to determine the outstanding tasks.

8.5.2 Task Completion

Calculating how far a pair reached in a given task can be one indicator of task performance. The participants were required to complete 13 sub-tasks. Two pairs from each condition completed the overall task within the allocated 35 minutes. The same two pairs completed the overall task in both co-located and distributed settings. The average number of sub-tasks completed in the co-located condition (10.14, SD=1.8) was higher than the average number of sub-tasks completed in the distributed condition (9.42, SD=1.83). In both conditions there were instances where both participants performed the same sub-tasks. This occurred an average of 0.14 times (SD= 0.36) in the co-located setting and an average of 0.28 times (SD= 0.61) in the distributed setting. In both conditions sighted participants performed a slightly higher number of sub-tasks.

Table 8.1 below shows the percentage number of sub-tasks completed, sub-tasks completed together, uncompleted sub-tasks and the sub-tasks that overlapped in both conditions. Completing the sub-tasks together rarely occurred in the co-located condition, and never occurred in the distributed setting.

Percentage number	**Co-located condition**	**Distributed condition**
Sub-tasks completed by the Sighted participant	45%	43%
Sub-task completed by the VI participant	33%	32%
Sub-task completed together	1%	0%
Uncompleted sub-tasks	21%	25%
Overlapped sub-tasks	1%	2%

Table 8.1 Summary of sub-tasks completed by participants in both conditions.

8.5.3 Participants' Team Performance Satisfaction Levels

In the post-study questionnaire participants were asked to rate their performance and communication levels, with 10 being the most satisfying and 1 being the least satisfying. The response showed high satisfaction levels in response to all three questions, as shown in table 8.2. The average satisfaction level for performance was 7.9, and the average satisfaction rating for communication level was 8.01. Sighted users rated their communication level lower in the distributed condition, highlighting the need for an audio alert for the team chat tool. They suggested that the instant messaging tool could be improved to support the process, as currently there is no alert to notify them when a new message has been received.

	Co-located condition		Distributed condition	
	VI participants	**Sighted participants**	**VI participants**	**Sighted participants**
Performance	7.78 [1.25]	9 [1.47]	7.14 [1.46]	8 [1.47]
Communication	8.28 [1.32]	8.92 [1.38]	7.35 [1.54]	7.5 [1.54]

Table 8.2 Participants' performance and communication satisfaction levels. (Average [SD]).

8.5.4 Division of Labour

There were significant differences in the way participants worked together, and the approaches used to divide the labour in both conditions. In the co-located setting it was observed that pairs usually employed the 'divide and conquer' strategy (Morris, 2008) to divide the labour. As described in section 5.5.2 for study 1 pairs using this strategy in study 2 continued discussing the work together throughout the process, in spite of the fact that the main task had been divided into sub-tasks and assigned to each partner. Participants were observed asking their partner's opinion about results found or discussing several options retrieved with one another.

As described in the previous section division of labour appeared in two stages of the CIS process in the co-located setting (stage 1 and stage 3). Stage 1 was totally dedicated to discussion of the division of labour and reaching an agreement on how to organize the retrieved information. This discussion usually concluded with a clear decision about how the task was to be divided. In almost every pair, one participant led the discussion. In 10 out of 14 pairs the VI user led the discussion about the division of labour, in three pairs the sighted participant led this discussion and in one pair both participants contributed to the discussion equally.

As indicated in the description, the task required participants to plan a trip to three cities. The participants were required to collaboratively organize two or more activities and accommodation, as well as the travel arrangements between the three cities. The two approaches described in section 5.5.2 involved dividing the task between the partners. Ten pairs of participants chose to divide the task according to the nature of the sub-task; in which one participant performed booking related sub-tasks and the other participant performed activity-related sub-tasks. Four pairs of participants divided the work so each participant performed the sub-tasks related to one city; sub-tasks related to the third city were divided between them.

In the 10 pairs who divided the work according to the nature of the task, the sighted user performed the travel and accommodation bookings whilst the VI user organised the activities. The VI participants recruited in this study were fairly experienced web users, so they divided the labour in such a way to avoid sub-tasks they thought (based on previous experience), may take them a longer time to complete, as they may encounter inaccessible web forms. The other four VI users did not feel the need to avoid using hotel and flight booking websites. In the post-study interview the 10 VI users indicated that from their web use experience they knew that the majority of these types of sites have inaccessible web components and/or required a VI user to spend time finding workarounds for the access issues encountered.

In the distributed setting it was observed that the collaborators used the ‘brute force’ strategy (Morris, 2008). As described in section 5.5.2 in this strategy participants tend to work independently. In nine out of 14 pairs the VI participant led. In three pairs the division of labour was led by the sighted participant, and in two pairs the division of labour was discussed and agreed between both participants. In terms of the ways collaborators divided the labour, pairs used the approaches described in section 5.5.2. 10 pairs of participants divided the work according to the nature of the sub-tasks and four pairs of participants divided the labour according to the city. In the 10 pairs who chose the former approach, eight VI users suggested that their sighted partners perform the flight and hotel bookings so that the VI partner could avoid potential accessibility issues.

8.5.5 Information Exchanged between Pairs

In the co-located condition (as in study 1), partners communicated verbally. In the distributed condition participants used the Team Chat feature provided within SearchTeam. Participants exchanged group and workspace awareness information. On less common occasions they would discuss a matter related to the search task. In other words, their discussions would include supplied or requested information.

The supplied and requested information would either be group awareness information (i.e. their progress in IS activity) or workspace awareness information (i.e. updates they had made to the shared workspace). They usually notified each other about new information they added in the shared workspace, or about a post they commented on in the shared workspace. Using the coding scheme introduced in the methodology chapter (section 3.8.1), we analysed the information exchanged in the presence of an interface that provides a mechanism to support awareness. Examples of instances of information exchanged between participants are presented below, which are extracts of conversations in each condition:

Co-located condition- Verbal communication:

[VP, S6]: *Historical site in Bahrain, you look for that I will look for restaurants* (Category: Supplied related to group awareness)
[SP, S6]: *Now I can see what you added and I just add a post that says that this is in Beirut* (Category: Supplied related to workspace awareness)

Distributed condition- Team Chat dialogue:

[VP, S4]: *Done restaurants for the 12th* (Category: Supplied related to group awareness; participant is describing what he just did) *now doing historical site on 13th* (category supplied related to group awareness; participant is describing what he is doing)
[SP, S4]: *Great, I've just added the flight details from London to Rome.* (Category: supplied related to workspace awareness; the participant is describing what he just added in the shared workplace)

Table 8.3 provides the percentages of occurrences in the identified categories of coding. The highest proportion of information exchanged was related to supplied awareness information, while the proportion of requested information is low in both conditions. Supplied awareness information related to categories "what they are doing" or "what they just did," and these were the highest in both conditions.

15% of information exchanged in the co-located study and 13% of information exchanged in the distributed condition was related to the initial division of sub-tasks, which happened at the start of the session. In study 2 web accessibility issues were reported to the observer, while in study 1 they were reported to the other participant in the session. Therefore there were no instances recorded where a participant asked their partner for assistance. The reason for this could be that in study 2 participants were using the ACSZ system, for which they considered the observer to be responsible for issues that occurred, and so they reported the issues directly to the observer.

	Co-located condition	**Distributed condition**
Division of labour	13%	15%
Reviewing outstanding sub-task	8%	5%
Request for assistance in solving the web accessibility issue	0%	0%
VI participant requesting help from sighted participant in viewing a large amount of information	0%	0%
Supplied information	48%	65%
Requested information	13%	6%
Task-related discussion	10%	5%
Organizing information in the shared workspace	8%	5%

Table 8.3 Percentages of occurrences of each information exchange category.

To facilitate group and workplace awareness participants supplied and requested information related to IS activity and management of information in the shared workplace. Figure 8.1 shows in detail the proportion of supplied and requested information in both conditions. The information supplied and requested relating to group awareness is much higher than the information supplied and requested relating to workspace awareness:

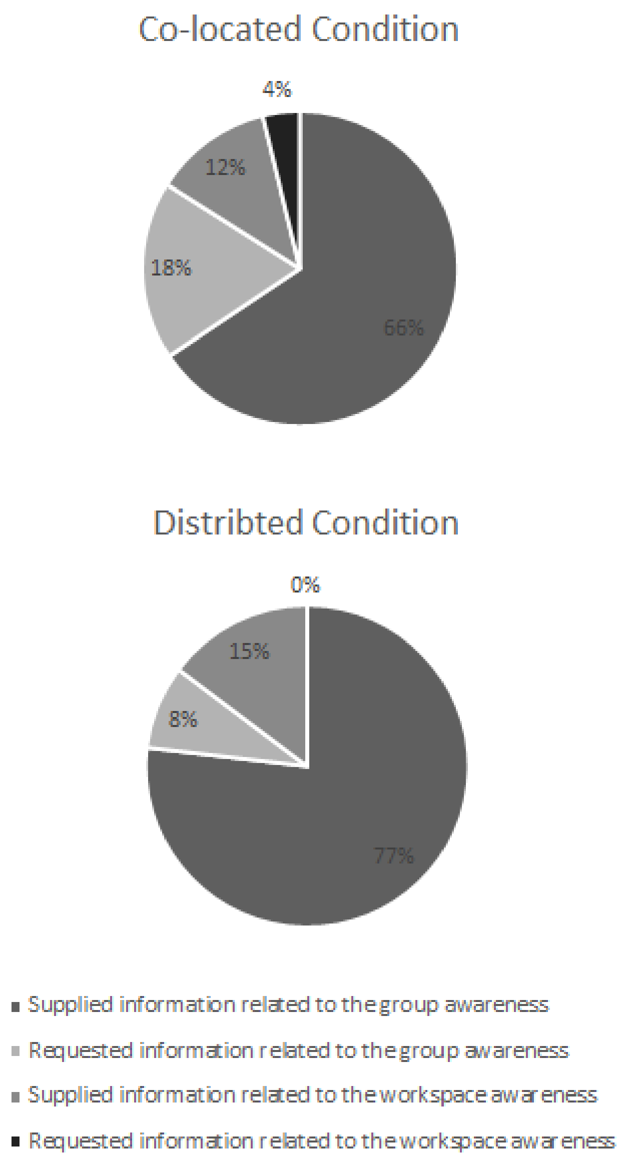

Figure 8.1 Percentage numbers of instances of information supplied and requested.

In all studies, as shown in table 8.4, the average number of pieces of information supplied by sighted users is higher, though the difference is slightly greater in the co-located condition. The average number of pieces of information requested by VI participants is higher in both conditions. The difference is significant in the distributed condition ($\chi2= 5.643$, $p= 0.017$). The average amount of information relating to group awareness supplied and requested is much higher than the average amount of information relating to workspace awareness:

			Co-located condition	Distributed condition
Supplied information	VI participant	Group awareness	2.42 [2.21]	2.07 [1.59]
		Workspace awareness	0.5 [0.65]	0.64 [1.33]
	Sighted participant	Group awareness	3.86 [3.01]	3.14 [1.87]
		Workspace awareness	0.64 [1.15]	0.35 [0.74]
Request information	VI participants	Group awareness	1 [1.17]	0.5 [0.75]
		Workspace awareness	0.14 [0.36]	0
	Sighted participants	Group awareness	0.78 [1.05]	0.071 [0.26]
		Workspace awareness	0.21 [0.42]	0

Table 8.4 Number of instances of information supplied and requested. (Average [SD]).

Looking at the sub-categories of the supplied and requested information relating to group awareness information in figure 8.2 of both conditions, the sub-categories that were recorded most frequently are from the supplied category. Both "notification of task completion" and "what I am doing" were recorded the highest number of times in both settings. The differences in occurrences between all categories was not significant in the co-located setting, with the chi-square test giving ($\chi 2$ =5.17, p=0.075) in the co-located condition. The differences were more apparent in the distributed setting with the chi-square test giving ($\chi 2$= 22.32, p= 0.001).

In terms of requested group awareness information, the "what you are doing" sub-category is recorded the most frequently of the three sub-categories recorded relating to information requests. It appeared significantly higher than other sub-categories in both conditions, with the chi-square test giving ($\chi 2$= 15, p= 0.002) in the distributed condition and ($\chi 2$= 12 and p= 0.007) in the co-located condition.

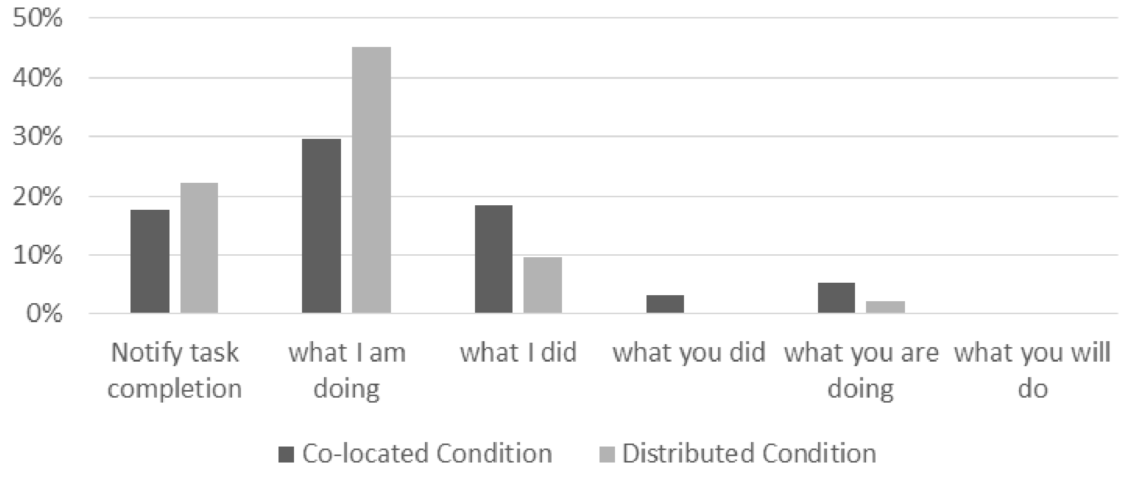

Figure 8.2 Percentage of group awareness supplied and requested information.

In the sub-categories of supplied information relating to workspace awareness, the highest category in both conditions, is “what I did” as shown in Figure 8.3. The difference is not significant in the co-located condition with the chi-square test giving (χ^2= 5.33, p=0.969). As can be seen in figure 8.3, the difference is more apparent in the distributed condition with the chi-square test giving (χ^2=8, p=0.018). Participants only requested information related to workspace awareness in the co-located condition. Two sub-categories occurred: “Did you complete” and “what you will do”. The difference was not significant, with the chi-square test giving (χ^2= 3.8, p=0.28). In this sub-category one participant would usually notify their partner about adding a post or link or creating a folder.

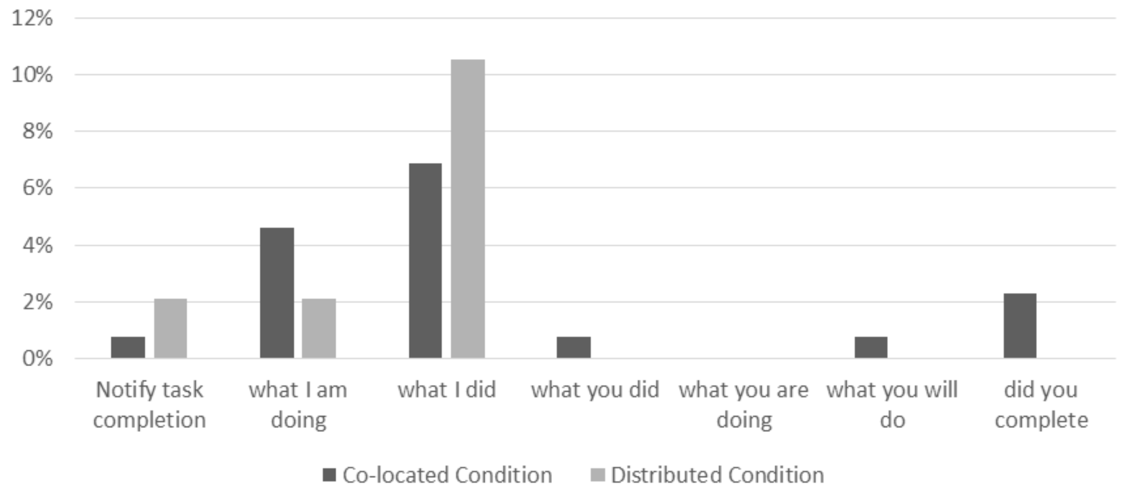

Figure 8.3 Percentages of workspace awareness supplied and requested information.

Individual differences related to the amount of information exchanged were noted in the co-located condition. In the co-located condition familiar pairs (S1, S6, S11) exchanged in total more information than all other pairs in the co-located condition. S10, which also consisted of a familiar pair of participants, the total amount of information exchanged by this pair is less than the average of the total amount of information exchanged by the pairs in this study. In the distributed condition, as shown in figure 8.4, there was no apparent differences in the amount of information exchanged between the familiar pairs (S1, S6, S10 and S11) and the other pairs in this study.

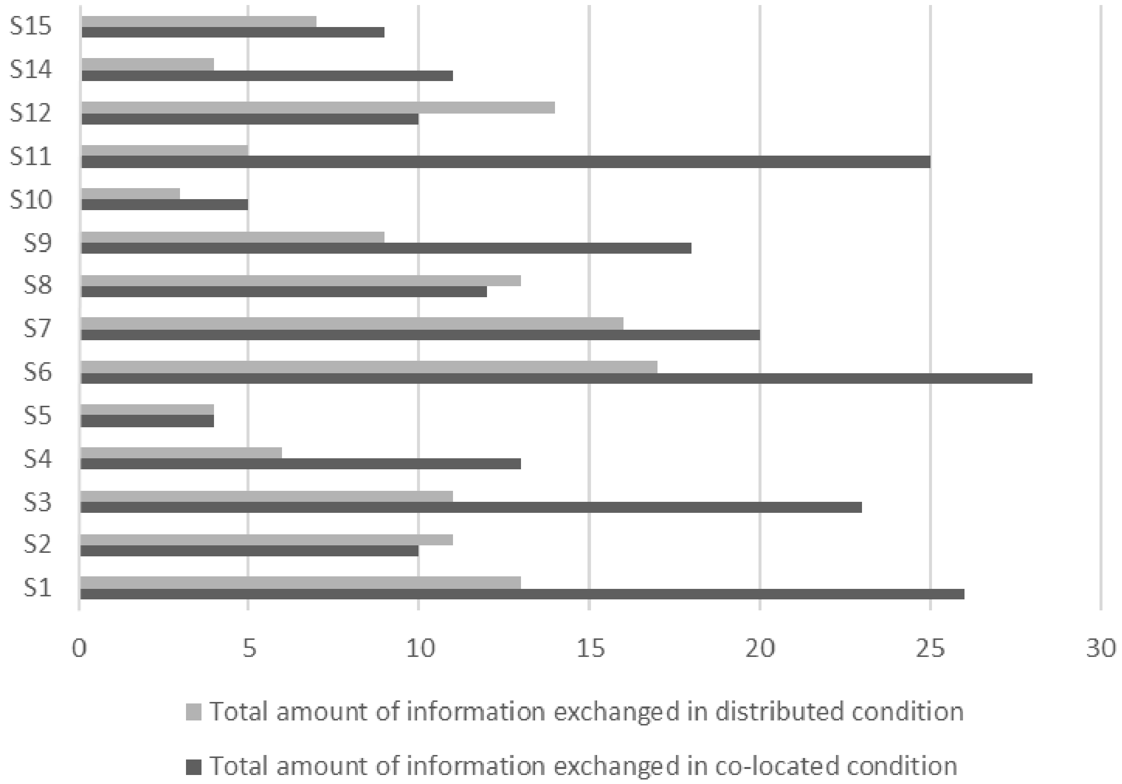

Figure 8.4 Total amount of information exchanged by each pair in both conditions.

8.5.6 The Usage of Received Information

When looking at the usage of received information and what the receiver does with it, as shown in table 8.5, there are two major differences between the conditions. Firstly, the amount of critical information was low in the distributed setting compared to the co-located setting. Secondly, the amount of information exchanged to avoid duplication of effort was higher in the distributed setting.

	Category A	**Category B**	**Category C**	**Category D**
Co-located Condition	15%	27%	24%	34%
Distributed Condition	10%	23%	14%	52%

Table 8.5 Percentages of each category in the usage of received information.

We looked into sessions with the highest and lowest sub-task performance from each condition. Table 8.6 shows the sum of the average number of pieces of information exchanged by category in the sessions with the highest and lowest sub-task performance from each condition. The criteria employed to rank participants' performance is described in 5.5.7.

		A	B	C	D
Co-located condition	**Highest performance**	3	10	9	14
	Lowest performance	4	6	4	7
Distributed condition	**Highest performance**	3	9	6	12
	Lowest performance	1	3	2	8

Table 8.6 Total occurrence of each category in the sessions with highest performance and lowest performance.

There were no statistically significant differences between pairs who performed well and pairs who performed poorly in the co-located setting, with chi-square test (χ_2 = 1.55, p= 0.66). In the top performing pairs in the co-located setting the total pieces of information exchanged to avoid duplication of effort (category D) was the highest of all categories. Additionally, the amount of information exchanged that was needed but not critical (category B) was fairly high. Information that was filed away by the receiver (category A) was the lowest. The total amount of critical information (category C) exchanged was higher in the highest performing teams. In teams who performed poorly (category D) it was also the highest; yet much lower than the sum of (category D) occurrences in the team that perform poorly. The sum of information needed but not critical (category B) was high, as was the amount of critical information exchanged (category C).

There were no statistically significant differences between pairs who performed well and pairs who performed poorly in the distributed setting, with chi-square test (χ_2 = 1.13, p=0.769). However there are some notable differences between the two groups. When looking into the sessions where performance is relatively low in the distributed condition, the amount of information exchanged to avoid duplication (category D), and the amount of needed but not critical information (category B) was relatively high in comparison to the other two categories.

8.5.7 The CIS Activity of Individual Teams

So far the results section has reported the measures sampled from the 14 pairs of VI and sighted users. This section reports notable differences observed in individual pair's task performance and information management in both conditions. A few differences were observed and are worth noting and discussing.

In terms of task completion the difference between the numbers of sub-tasks completed by the pairs in each condition was small for most of the pairs as shown in figure 8.5, where the pair would either complete the same number of tasks in each condition or complete one or two more sub-tasks in one condition. The most apparent differences were noted in S4, S12, S11, where the pair performed better in the co-located setting, and in S7 where the pairs performed better in the distributed setting.

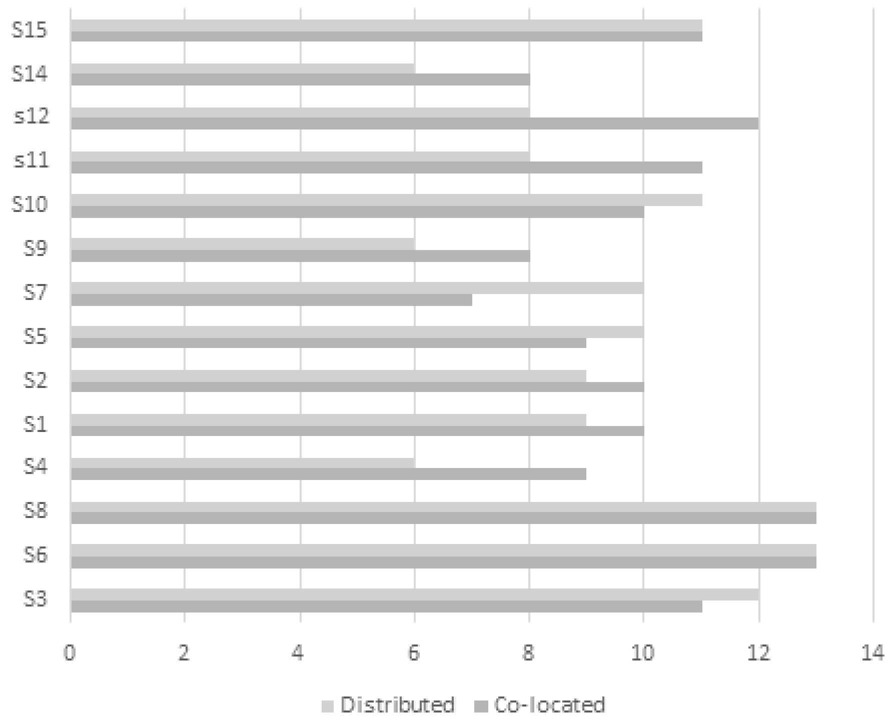

Figure 8.5 Differences in the sum of the sub-tasks completed by each pair in both conditions.

For teams who performed better in the co-located setting, only one accessibility issue was reported by S11. For S4, the VI participants' task performance was low in both settings. However his task performance was lower in the distributed setting. The participant did not face any accessibility issues. It was observed that he spent a long time browsing each website. For instance, he spent over six minutes browsing one of the websites. The total time spent browsing websites was very high in comparison to other pairs. He commented that he usually spent a long time browsing a website that he was accessing for the first time in order to understand the structure of the website. He explained that it allows him to reach the required information more easily. For S11 there seemed not to be an issue; However in the post-study interview the VI participant stressed that he prefers verbal communication over chat messages. In S12 the sighted user completed fewer sub-tasks in the distributed setting. There were no apparent difficulties encountered. However it was observed that the sighted participants seemed not to notice that a chat message had arrived. This is likely to have had an effect on the pair's communication. As described in the appendix, he usually checked the team chat panel when he completed a sub-task (i.e. added a post or saved a link). For S7 participants completed more sub-tasks in the distributed setting. The difference was more apparent between the number of sub-tasks the sighted user completed in the distributed setting and the number of sub-tasks she had completed in the co-located setting; there seems not to be an obvious issue underlying such a difference in task performance.

8.6 Chapter Summary

This chapter described an observational study in which VI and sighted users performed collaborative search activities using ACSZ. It described the results from the collaborative perspective. It firstly examined the process as a whole and how the pairs interacted together to perform the activities in section 8.5.1. It reported measures of the tasks completed by the pairs in section 8.5.2 and their satisfaction levels in section 8.5.3. It describes approaches in which the labour was divided in section 8.5.4. The chapter explores how awareness information was provided by users in the presence of an interface that supports workspace awareness in section 8.5.5 and 8.5.6. Finally the chapter provides an overview of individual teams' collaborative activity in section 8.5.7. This chapter's main contribution is providing an analysis of VI and sighted users CCIS activity and their interactions with each other. The following chapter will examine the results of study 2 from an individual participant's perspective.

Chapter 9 Study 2: CCIS using an ACSZ: User Interaction Results

9.1 Introduction

To answer study 2's research questions, as discussed in section 8.3, we need to analyse individual behaviour and user interaction aspects in the study. This includes the ways users searched for information, both collaboratively and individually, and their interactions with the interface. This chapter discusses the single user-focused dimension. It starts by presenting findings related to information seeking behaviour in section 9.2. The chapter then describes the user experience aspect of the study, which includes the usability of the components and features in section 9.3. The chapter then looks into VI users' interactions with the JAWS scripted features and JAWS system settings employed in section 9.4. Section 9.5 provides an analysis of the single user issues encountered by both VI and sighted users using the interface.

9.2 The Individual Process

In this section we report and compare findings in relation to the search behaviour of participants at different stages of the IS process (section 9.2.1.). This section is followed by a description of the time spent performing each stage, and a discussion of the differences that occurred in the different stages of the IS process.

9.2.1 The Stages of IS

Similarly to study 1 study 2 looked at the stages of IS. In study 2, the separate stages of IS were undertaken individually. Nevertheless some incidents were recorded where participants suggested queries to their partners in the co-located setting. We also observed incidents in which participants would view search results their partners are viewing (using the past search feature).

Query formation: The average length of initial queries entered by VI participants in the co-located condition (3.06 words, SD=0.56) was significantly longer than the average length of initial queries entered by sighted participants (2.03 words, SD= 1.00) at (t(25)=3.33, p=0.002). In the distributed setting the average length of initial queries entered by VI participants (2.75 words, SD= 0.59) was also longer than the average length of initial queries entered by sighted users in the distributed setting (2.46 words, SD= 0.59). However the difference is not significant at (t(25)=1.3363, p=0.19). Participants sometimes suggested query keywords for his/her partner. This only occurred in the co-located setting with an average of 0.33 instances (SD= 0.48). It occurred 1 time in four co-located sessions, therefore it did not have a major distorting effect on the findings relating to average length of initial queries.

Results exploration: In the co-located condition the average number of search results viewed by VI participants was lower (2.92 search results, SD= 2.23) than the average number of search results explored by sighted participants (4.64 search results, SD=2.52). However the difference was not significant at (t(25)=1.34, p=0.19). Three VI participants [VP, S5, S7, and S11] did not explore any search results and relied solely on the summary available in the search results page.

In the distributed condition the average number of search results viewed by VI participants (3.28 search results, SD= 3.04) was significantly lower than the average number of search results explored by sighted participant (5.69 search results, SD= 2.59)[36] at (t(25)=2.11, p=0.04). Similar to the co-located condition, we observed three VI participants [VP, S2, S3, S5, and S15] and one sighted participant [SP, 12] who did not explore any search results.

The average number of search results viewed collaboratively was 0.28 search results (SD= 0.611) and only occurred in two cases in the co-located condition. There were no instances recorded for search results viewed collaboratively in the distributed setting. There were also some incidents in which participants were observed viewing search results their partners were viewing (using the past search feature). This only occurred in the distributed setting an average

[36] The average number of search results explored by sighted participant in distributed condition before removing outliers 6.71 (SD= 4.56)

of 0.14 times (SD= 0.36) by VI participants and an average of 0.21 times (SD= 0.80) by sighted participants.

Query Reformulation**:** It was observed that this stage is undertaken individually, and it was done more frequently by sighted participants, though the differences were not significant at ($t(25)= 2.009$, $p=0.05$) in the co-located condition and ($t(25)=1.92$, $p=0.066$) in the distributed condition. In the co-located condition the average number of times a query was reformulated by VI participants was 0.35 (SD= 0.633), and the average number of times queries were reformulated by sighted participants was 1.23 (SD= 1.58). In the distributed condition the average number of times a query was reformulated by VI participants was 0.5 (SD= 0.64) and the average number of times a query was reformulated by sighted participants was 1.38 (SD= 1.85).

Search Results management: To explore the completeness of information stored we reviewed the information stored by each participant and verified that each piece of information retrieved has been stored in the appropriate place. In all sessions, pairs managed to store all information found in the corresponding folders. In two sessions, one in the co-located and one in the distributed condition, it was observed that one pair missed out saving one piece of retrieved information. In the co-located setting, it was the sighted participant who missed storing a website link, in the distributed setting, it was the VI participant who missed storing a website link. However there was no apparent reason for that to occur. The participants used a combination of features to organize and store information. Section 9.3.2 describes in more detail the interaction with the features and the issues encountered; section 9.3.3 continues by discussing approaches participants employed to store retrieved results.

9.2.2 Time Intervals

We observed time spent by participants on each of the stages of IS, as shown in table 9.1. That is in addition to time spent handling an error, and time spent switching from one application to another. For entering the search query terms there were no differences in the average time spent entering search terms. The stages in which variation in time spent was most evident are viewing search results, browsing search results websites and managing retrieved information. As mentioned in the previous section, a number of participants did not browse any websites, and hence spent a longer time on the search results webpage and managing stored information. The high standard deviation values recorded in these three stages reflects the variation of recorded participant behaviours.

There is a significant difference between the average times spent viewing search results pages in the co-located setting when viewing the search results page. VI participants spent an average of 6:38 minutes while sighted participants spent an average of 3:42 minutes at (t(12) =2.48, p= 0.0286). The difference was even bigger in the distributed setting, where the average time spent viewing search results pages by VI participants was 10:13 minutes, and 3.29 minutes for sighted participants at (t(13)= , p=0.01). In this stage, VI participant [VP, S7] spent a considerably longer time (a sum of 29 minutes) browsing the webpages, while the next highest value is a sum of 11:30 minutes for [VP, S15] and a sum of 10:20 minutes for [VP, S5]. This outlier highlights individual differences in participants' usage patterns in this stage.

In terms of time spent browsing websites, as mentioned in the previous section 9.2.2, three VI participants in both conditions and one sighted participant in the distributed condition preferred not to browse any websites and relied solely on the search results webpage. Additionally for one VI participant [VP, S15] and one sighted participant [S, S11] in the co-located condition and one sighted participant [SP, S11] in the distributed condition, the total time spent browsing websites was less than 2.5 minutes. On average it was observed that VI participants spent on average (7:45 minutes) less time than their sighted peers (11:05 minutes) at (t(12) = 2.67, p= 0.204) in the co-located condition. Similarly in the distributed setting the average time spent browsing websites by VI participants (07:07 minutes) was lower than the average time spent browsing websites by sighted participants (10:45 minutes). The difference was not significant in the distributed setting at (t(12)= 1.9, p= 0.08).

VI participants spent slightly more time than their sighted partners managing and organizing retrieved information (table 9.1). The difference is not significant in both the co-located (t(13) =

0.702, p=0.48) and distributed condition (t(13)= 0.605, p= 0.54)). VI participants spent on average a longer amount of time (55 seconds) than their sighted peers (23 seconds) in the co-located condition in handling errors. Likewise in the distributed setting, the difference is relatively high as VI participant spent slightly more time than their sighted partners. The difference was not significant in either setting with the co-located setting at (t(12) = 1.06, p= 0.3) and the distributed setting at (t(12) = 1.04, p=0.31).

	Co-located condition		**Distributed condition**	
	VI participant	**Sighted participant**	**VI participant**	**Sighted participant**
Entering query term	01:31 [00:45]	01:34 [00:55]	01:29 [00:56]	01:20 [00:45]
Viewing search results page	06:38 [03:37]	03:47 [03:11]	06:30 [2:17][37]	03:29 [01:30]
Browsing websites	07:45 [03:32]	11:05 [05:19]	07:45 [03:34]	10:45 [05:18]
Managing information	07:02 [04:28]	05:22 [04:29]	07:28 [05:38]	06:20 [04:15]
Encountering error	00:55 [00:17]	00:23 [00:51]	00:56 [00:23]	00:28 [00:29]
Chat	00:34 [01:08]	00:28 [00:57]	05:31 [03:45]	04:27 [01:30]
Switching from one application to another	00:30 [00:33]	-	00:29 [00:23]	-

Table 9.1 Time spent in each stage in both conditions in minutes. (Average [SD]).

[37]The average time VI participants spent viewing search results page in distributed setting before removing outlier is 8:08 minutes (SD= 6:30).

9.3 User Interaction

In this section we discuss participants' interactions with ACSZ. Participants reported that their experience with the interface was pleasant and their satisfaction level was fairly high, as shown in table 9.2. A number of VI and sighted participants highlighted the point that the integration of a chat tool and shared workplace certainly made the CIS process much easier. In the semi-structured interviews, 13 sighted and 10 VI participants expressed that even though it was their first time for them to use the interface, they felt the process was easier than using separate applications. The benefit of providing an integrated solution that allowed users to organize and communicate retrieved information was highlighted by both VI and sighted participants. VI participants found that "*it made them switch less between applications and save more time*" [VP, S6]. Another participant commented "*it's certainly easier than launching my email client and sending an email multiple times during a session*" [VP, S8]. Sighted participants found that this interface supported "*easier and better communication which meant a better team working*" [SP, S6]. Knowing their partner's activity made them "*become more confident while moving on in with the task*" [SP, S15]. The purpose of the interface seems to be of interest to the participants, and one participant commented "*the idea of collaborating with mates is excellent*" [VP, S6]. Another VI participant, who is a technology specialist, described that the idea of the interface "*has certainly got potential*" [VP, S4]. Two VI participants [VP, S6] and [VP, S2] and one sighted participant [SP, S2] requested that we send them the web address of the commercial website SearchTeam following completion of the sessions.

User satisfaction level	**VI participants**		**Sighted participants**	
	Average [SD]	Mode	Average [SD]	Mode
Interface ease of use	7.07 [1.43]	8	8.28[1.63]	10
Interface accessibility	6.92 [1.77]	8	-	-

Table 9.2 Satisfaction levels with the usability and accessibility of ACSZ. (Average out of 10).

The importance of training and learning through practice was one of the major points that was highlighted by VI participants. They commented that it is "*just about practicing how to use it*" [VP, S6]. Other participants pointed out that "*it would be easier once we get up and running with it*" [VP, S4]. They found that lack of familiarity was the main reason that slowed them down; one participant commented "*The learning curve kind of slowed me down. But that's a matter of getting used to it. If I had more training and time I would have done better*" [VP, S3]. Three VI participants thought the CIS process was harder, using a new solution emphasizing the fact that usually web interfaces tend to be "*a bit cluttered* " [VP, S14]. One sighted participant and one VI participant thought it was about the same level of difficulty (as using separate, self-chosen applications, as in study 1).

The overall accessibility of the interface was acceptable to the participants; they expressed that "*it is fairly accessible despite some inconsistency*" [VP, S4] and that "*The interface is very practical, with a few issues that can be improved*" [VP, S8]. On overcoming some of the accessibility issues encountered such, as navigating the add post form, participants commented in the post-study interviews that "*it is a matter of getting used to it*" [VP, S3]. In the rest of this section, we investigate participants' interactions with the interface. We start by reporting participants use and access of the interface's major components. We refer to the search tab, folder tab, team chat modal dialogue form, and recent activity region as the major components. This is followed by a detailed description of the use of features in section 9.3.2, and observed usage patterns when storing information retrieved in section 9.3.3. This section concludes by outlining approaches users employed to facilitate awareness in section 9.3.4.

9.3.1 Interaction with the Major Components

We recorded the number of times each major component was accessed by participants (table 9.4). We refer to the search tab, folder tab, team chat modal dialogue form, and recent activity region as the major components. In this section we describe participants' interaction with these major components.

	VI Participants		Sighted Participants	
	Average [SD]	**Mode**	**Average [SD]**	**Mode**
Search Tab	8.3 [2.12]	10	8.07 [1.94]	10
Team Chat	8.85 [0.77]	8	9.7 [0.61]	10
Folder Tab	8 [1.79]	10	9.5 [1.77]	10
Recent Activity	7.85 [2.34]	10	7.25 [2.26]	10

Table 9.3 Satisfaction levels with the major component. (Average out of 10).

	VI Participants	Sighted Participants
Search tab	7.03 [2.34]	7.85 [3.64]
Folder tab	3.107 [2.61]	5.6 [3.01]
Team chat	4.25 [4.71]	5.42 [5.62]
Recent activities	1.32 [1.94]	0.64 [1.06]

Table 9.4 Summary of each major components number of accesses. (Average [SD]).

Search tab: The search tab was the most accessed component as it is at the core of the CIS process. It was accessed an average of 7.03 times (SD= 2.34) by VI users and 7.85 times (SD= 3.64) by sighted users. The differences between the number of accesses of the search component by both groups in both settings was not significant, with a chi-square test at ($\chi2 = 1.26$, $p = 0.26$). The number of accesses was slightly higher in the distributed setting (as shown in table 9.5). This is consistent with the fact that participants explored slightly higher numbers of web search results in the distributed setting. The participants were fairly satisfied with its ease of use (as shown in table 9.3). They stated that it was *"easy to use*" and "*pretty similar to usual search engines*" [VP, S8]. Although the majority of participants rated its ease of use highly, both VI and Sighted participants highlighted a design issue which affected their IS activity. As mentioned in section 9.2.1 and 9.2.2 some participants preferred not to browse the web search results. The reason behind this behaviour is that when a user clicks on a search result link the website opens in a new window. Four VI and three sighted participants reported that opening web search results certainly confused them; they stated that "*It would be preferable to have the website open in the same page*" [SP, S3]. Due to this issue they preferred to save search results without actually opening the website. Apart from the participants who chose to rely entirely on the information available on the search results page and save a website according to that (as report in section 9.2.2) three other VI participants spent in total less than 2.5 minutes browsing website results.

Team chat: In the distributed setting the average number of times participants accessed team chat was higher than the average number of times participants accessed the search engine tab, as team chat was the main communication tool. The average number of times VI participants accessed the team chat dialogue window was 7.71 times (SD= 4.33) and the average number of times sighted participants accessed the team chat component was 10.28 times (SD= 3.64). The difference of ($\chi 2= 4.01$, $p= 0.045$) was significant for two reasons. Firstly it was not completely straightforward for VI participants to reach the team chat using JAWS. As described in section 7.10.2 the user is required to navigate in a certain way to reach the team chat modal dialogue form using the JAWS built-in search. Secondly the VI participants used the Reach Chat message keyboard command to read the chat messages without actually accessing the team chat modal dialogue form. This had the effect of lowering the number of times VI users needed to access the team chat modal dialogue form. The majority of VI participants would always use the keyboard command to read the messages and would only navigate to the actual team chat modal dialogue form to send a message.

Despite having a JAWS script command key that allowed them to easily read the received messages, VI participants were not as satisfied as their sighted peers with this component, though both satisfaction levels were high as shown in (table 9.3). Seven VI participants stressed that its location on the page was hard to find. One of them commented that "*If you are a good* *internet user, you might get lost*" [VP, S10]. Another participant said "*it would be quite a good thing to have a hot key to just take you to it!*" [VP, S1].

Folders tab: The average number of times sighted participants accessed folders tabs (5.6 times, SD= 3.01) was higher than the average number of times VI participants accessed folders tabs (3.1 times, SD= 2.61). In addition to being very satisfied with its ease of use, participants were fairly enthusiastic about the idea of having the ability to organize the information retrieved in the shared workplace in folders.

Recent activity region: The average number of times sighted participants accessed the recent activities region by either scrolling down the page to view it or clicking on a hyperlink associated with one of the updates was significantly lower (0.64 times, SD= 1.06) than the average number of times VI users access the recent activities region by reaching it through the screen reader (1.32 times, SD= 1.94) at ($\chi 2$=6.56, p=0.01). However since the details of recent activities was always present on the webpage, it was hard to know whether a sighted participant is actually checking the recent activity region or not. Therefore we asked users in the post-study interviews to estimate how often they visited the recent activity region during the search tasks. Seven VI and five sighted participants described that they frequently checked this region. Four VI and four sighted participants said that they navigate to this region once or twice during each task; three VI and five sighted participants said that they have not used it at all.

The post-study interviews confirm that the recent activity region was very well received among VI participants; they expressed that "*it was very easy to reach*" [VP, S2, S4, S11]. To be able to see updates to folders VI participants used the recent activity region to have an overview of all updates in folders instead of navigating to each folder and accessing it to view the changes. It "*provides an overview*" [VP, S4] and "*activity logs of both collaborators*" [VP, S15] which was "*very helpful to know the progress of work*" [VP, S9]. One participant commented "*I just know that I have checked it far more than I have checked the chat or the folders because it was just so easy to go there*" [VP, S2]. Conversely, sighted users comments in the post-study questionnaire confirmed that they rarely used it. The reason they did not use it as often is that they were "*always notified of the changes through popup messages*" [SP, S12]. One sighted participant commented "*I used it whenever communication was hard via chat or when my partner was not replying promptly*" [SP, S15]. VI participants' satisfaction levels were slightly higher than the sighted participant satisfaction levels.

	VI participant		**Sighted participant**	
	Co-located condition	**Distributed condition**	**Co-located condition**	**Distributed condition**
Search tab	6.78 [2.63]	7.28 [2.09]	7.0 [3.76]	8.71 [3.45]
Folder tab	2.71 [2.33]	3.5 [2.90]	5.42 [3.0]	5.78 [3.11]
Team chat	0.78 [1.25]	7.71 [4.33]	0.57 [1.28]	10.28[3.64]
Recent activities	0.85 [1.02]	1.78 [2.51]	0.5[1.01]	0.78 [1.12]

Table 9.5 Number of accesses to major components in both condition. (Average [SD]).

9.3.2 Interaction with the Features

The interface provides features related to storing and managing retrieved information. The interface provides a variety of ways to store information, as described in 7.8.2, and those features were demonstrated to participants during training. However due to time constraints on training, participants were only asked to perform the major tasks, which are searching the web, creating a folder, saving a link, adding a post, sending a chat message and adding a comment. Following the study sessions, they were also given time to explore the rest of the features as they wished. The remainder of this section presents data on how participants interacted with the features related to storing retrieved information. Tables 9.6 and 9.7 below show the usage of features.

	VI participants	Sighted participants
Create folder	1.25 [1.2]	1.96 [1.29]
Save link	3.35 [2.85]	3.15 [2.46]
Add post	0.85 [1.38]	2.21 [2.13]
Add comment	0.25 [0.79]	0.67[1.24]

Table 9.6 Summary of the use of features. (Average [SD]).

	VI participants		**Sighted participants**	
	Co-located condition	**Distributed condition**	**Co-located condition**	**Distributed condition**
Create folder	1.14 [1.09]	1.35 [1.33]	1.78 [1.05]	2.14 [1.51]
Save link	3.64 [2.95]	3.07 [2.84]	2.53 [2.25][38]	3.92 [2.55]
Add post	0.71 [1.2]	1.0 [1.56]	2.0 [2.28]	2.42 [2.07]
Add comment	0.28 [0.82]	0.21 [0.8]	0.85 [1.51]	0.5 [0.94]

Table 9.7 Number of times the features were used in each condition. (Average [SD]).

Create folder: In the shared workplace the create folder feature gave participants the ability to create folders and then post and store information into those folders. Although VI participants faced no accessibility issues while creating folders, the average number of times VI participants created a folder (1.25) was quite a lot lower than the average number of times a sighted participant created a folder (1.96). In fact, its ease of use was rated as 8.41 out of 10 (SD=1.06) by VI participants, and all sighted participants rated it 10 out of 10. The average number of times a VI participant created folders in the distributed setting (1.35 times) was slightly lower

[38] Average number of times "Save Link" feature was used by sighted participants in co-located condition (before removing outlier 3.91 (SD= 3.77).

than the average number of times a VI participant created folders in the co-located setting (1.14 times) at (t(25)=1.53, p=0.13). Similarly the average number of times a sighted user created folders in the distributed setting (2.14 times) was lower than the average number of times a sighted user created folders in the co-located setting (1.78 times) at (t(25)=1.29, p=0.207).

Save link: As shown in table 9.7 save link was the most used feature by both groups in both conditions. Participants found this feature useful and easy to use because "*they could save all needed websites into the specific folder from the search results without the need of navigating to the required folder*" [SP, S4]. Participants used it confidently and no errors or accessibility issues were recorded when using it. In fact in the usability questions in the post-study questionnaire, VI participants rated it on average 7.59 out of 10 (SD= 2.87) (Mode = 9) and sighted rate it on average 9.33 (SD= 1.37) (Mode =10).

There are a variety of ways in which participants utilized the save link function throughout the task. While some participants saved one link related to one piece of information, other participants saved more than one link and added comments and posts including specific information related to the saved link. The next section, 9.3.3, describes these strategies in detail and identifies participants' usage patterns when storing retrieved information using ACSZ.

Add post: As shown in table 9.6, the number of times sighted participants used the add post function is higher than the number of times VI participants used it. The difference is significant in both conditions with (t(12)= 2.27, p=0.03) in the co-located condition and (t(12) =2.27, p=0.04) in the distributed condition. In the pre-study training sessions, a number of VI participants experienced some difficulties when filling the add post form. The add post form navigation issue was detected while performing the accessibility review and reported in section 7.6.5. Another issue participants encountered detected in the accessibility review is the lack of alternative text for forms controls, also described in 7.6.5. Two edit boxes to be filled when adding a post were not labelled, which caused confusion. During training VI participants highlighted this was the hardest component to interact with. However they mentioned that they "*usually would get around such an issue with time*" [VP, S10], principally by remembering the number and order of controls on the form.

In the post-study questionnaire, participants marked add a post as the only issue with the interface in terms of accessibility. One participant commented "*it is pretty accessible. The only problem was with adding a post*" [VP, S9]. They thought that "*it probably could be done better by fixing the navigation issue*" [VP, S8]. Even though they highlighted this as an issue they would like to be improved, VI participants still gave this feature quite a high satisfaction rating 8.4 out of 10 (SD= 1.37) (Mode =9) in terms of its usability. They highlighted the fact that performing the sub-task was possible even with this issue.. One participant commented, "*once I understood how it worked it became a quite straightforward task*" [VP, S10].

Sighted participants did not have any issue while using it. In the post-study questionnaire, it was rated the most usable component with an average of 9.7 out of 10 (SD= 0.42) (Mode =10). One participant commented, "*adding posts made it easy to save websites that are important to the task and informing your partner about the importance of each saved website*" [SP, S5].

Add comment: This feature was not as extensively used as saving a link or adding a post. When participants wished to add additional information to the information they had already stored, they used the save link or add a post feature. In all sessions where participants used add comments, this feature was used to add additional information, except in one pair [S2] where they used it to comment on their partner's post.

9.3.3 Usage Patterns in Storing Retrieved Information

Despite the fact that the tool provided users with quite a simple and straightforward way to structure the information, as described in section 7.8.2., a number of approaches were observed in relation to how retrieved information was stored. In terms of the structuring and organization of folders, the majority (10 pairs) organized the retrieved search results in quite a structured way, by categorizing information into folders; three pairs chose to store all the retrieved information in one folder in a linear list in the same order that items were retrieved. In one pair

[S3] the sighted participant chose to structure the information he retrieved in folders, while his partner preferred to store them as a list in one folder. This pair completed the co-located task in this way. However while performing the task in the distributed setting, the VI participant [VP, S3] noticed the more structured approach being used by her partner [SP, S3], and after completing the first sub-task, she started to follow a more structured approach when creating folders. Each created folder is dedicated to a category of information retrieved. These categories include travel booking, accommodation, dining and activities.

In terms of posts and comments within folders the interface features were used to structure and store the retrieved information as follows:

1. Using one feature to store one piece of information (for example, adding a post or saving a link). This pattern of behaviour was found in the distributed condition in six pairs with both the VI and sighted users, and in seven pairs by the VI participants only. In the co-located setting, it was observed in five studies by both the VI and sighted participants, and in eight studies by the VI participants only.

2. Using two features to store one piece of information, such as saving a link then adding a post that contains details related to the link. This pattern of behaviour was recorded in four pairs in the distributed setting and three pairs in the co-located setting. It was only completed by the sighted participant in these pairs. Figure 9.1 presents a screen capture that illustrates this approach.

These two approaches employed a two-level hierarchy (folder level and post level) to structure the information retrieved:

3. A three-level hierarchy structure used two features but in a three-level structure, which is saving a link or adding a post and then adding comments with related details to it. One pair used this approach as their strategy to organize information and communicate. One partner would post a link or a piece of information, and they would also perhaps add additional information in the comments field. Additionally they used

this feature to communicate and to comment on the information they posted. This type of behaviour was also found in four pairs in the distributed setting and seven pairs in the co-located setting, but only by the sighted participant in these pairs. Figure 9.2 is a screen shot which demonstrates this approach:

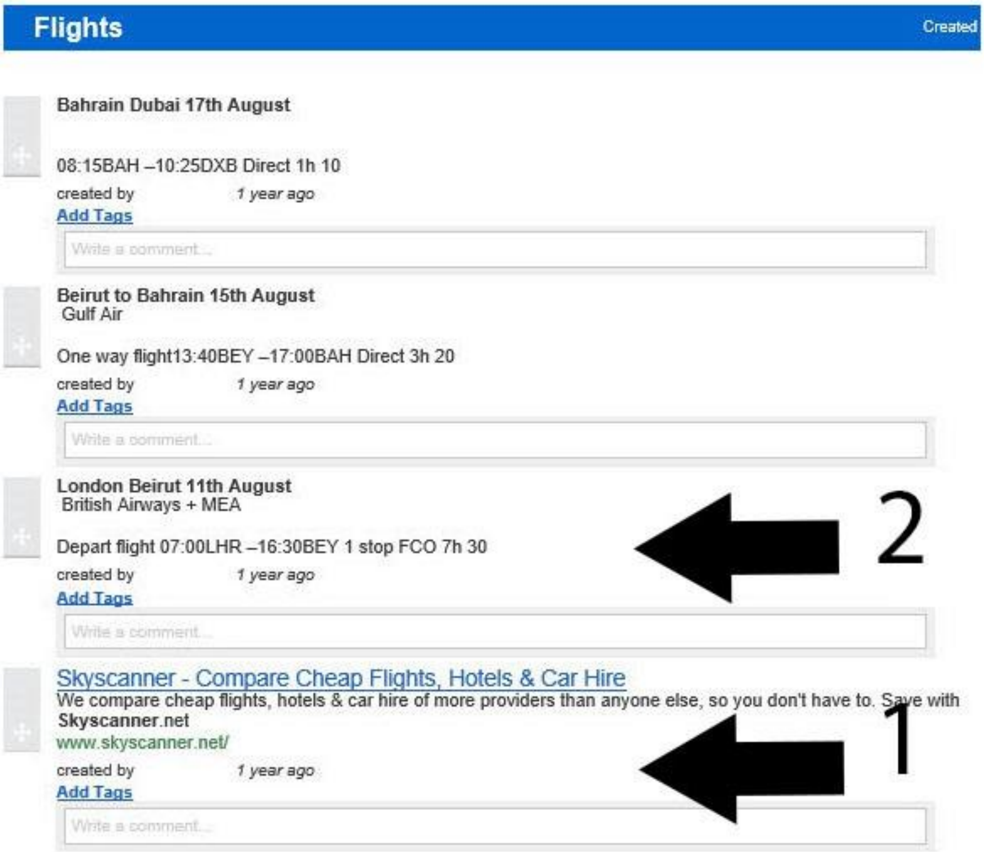

Figure 9.1 Using two features to store one piece of information.

(1) Saving the web link. (2) Adding a post with related details.

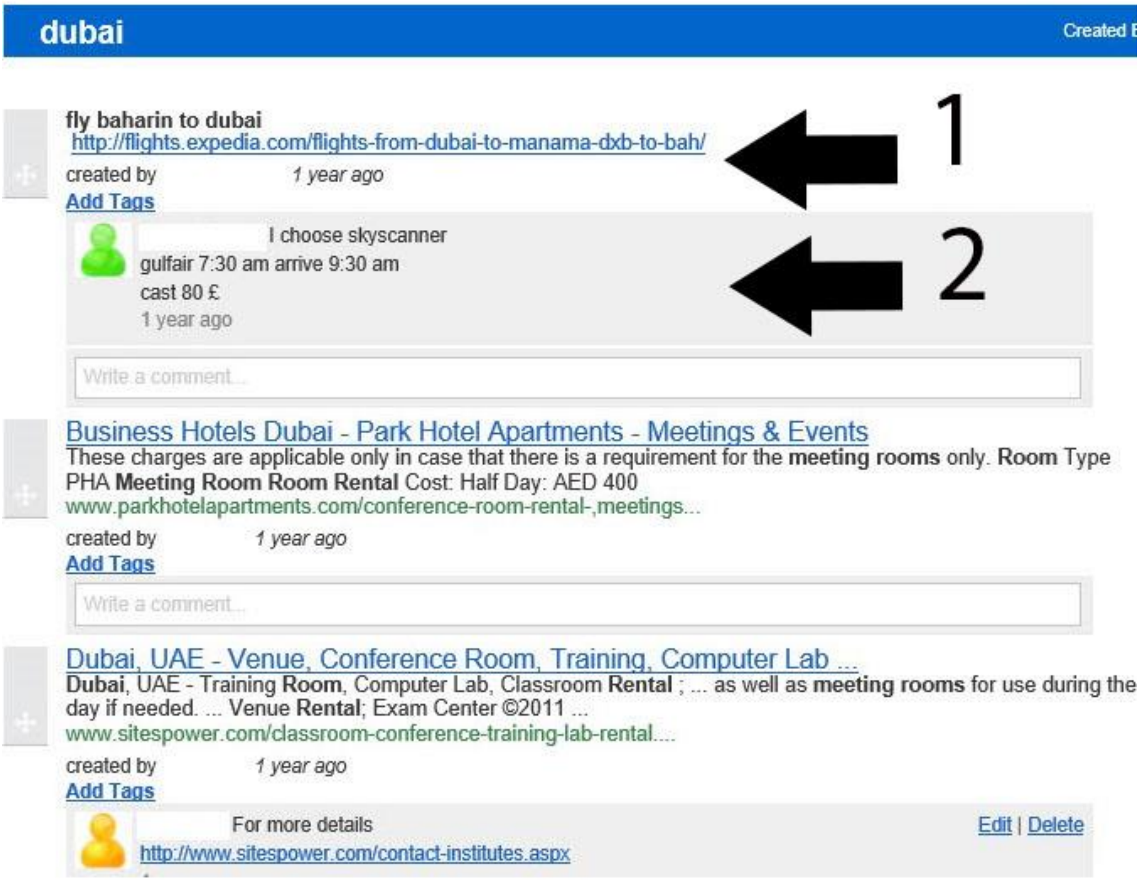

Figure 9.2 A three-level hierarchy structure.

(1) Adding a post with a website link. (2) Adding a comment with related details.

9.3.4 Usage Patterns to Facilitate Awareness

Other than communicating verbally in the co-located condition, and through the team chat in the distributed condition to facilitate awareness information, it was observed that after storing a post, participants would check the past searches or their partners' posts. Checking past searches rarely occurred; it only occurred in the distributed conditions in three sessions by [VP, S5 and S6] and [SP, S8]. The VI participants only used it once, and the sighted participants used it three times.

Checking their partner's posts by either navigating to the recent activity region or by checking the folders area was a more popular approach. It was observed that participants either used a combination of both approaches or used just one approach to keep track of their partner's activities by checking the recent activity region or the folders (area as summarized in table 9.8). It can be inferred that the majority of participants preferred to use one approach.

	Combination of two approach		**One approach**	
	Co-located condition	**Distributed condition**	**Co-located condition**	**Distributed condition**
Sighted participants	2	6	12	8
VI participants	2	2	12	12

Table 9.8 Summary of the number of times each approach is used to facilitate awareness.

Table 9.9 shows the number of participants using each approach and the average number of times each approach is used. 50% of VI participants viewed their partner's posts via the recent activity region in both conditions. The average frequency of access was at its highest in the distributed setting. The larger proportion of sighted participants viewed their partners posts through accessing the folders in which the posts were added.

		VI participant		**Sighted participants**	
		Number of participants	**Average [SD]**	**Number of participants**	**Average [SD]**
Co-located condition	**Recent activities**	7	1.71 [0.75]	3	2.33 [0.57]
	Folders	5	1.4 [0.55]	10	2.6 [0.84]
Distributed condition	**Recent activities**	7	1.57 [2.51]	6	1.83 [0.98]
	Folders	5	1.8 [1.3]	11	2.54 [2.21]

Table 9.9 Summary of the number of accesses to the recent activity region and the folders tab.

9.4 VI Users Interactions with Interface Enhancements

Four features were added through the use of JAWS scripts and JAWS settings to enhance users' experience of the interface. These features are described in detail in section 7.10. Specifically this section discusses participants' interactions with the enhancements. We structure this section according to the type of enhancement made (as in section 7.10). We start with describing participants' interactions with awareness features, followed by discussing the features introduced to enhance navigation.

9.4.1 Interaction with Awareness Enhancements

Following the study we asked participants to rate how satisfied they were with the two notification alerts and the JAWS script commands. The average satisfaction level with the new chat message notification (8.5 out of 10, SD= 1.50) (Mode = 8) was slightly higher than the average satisfaction level of a new post notification (7.5 out of 10, SD= 2.29) (Mode = 7). The fourth feature was a JAWS Script which is initiated by a shortcut key that repeats the folder update messages. Although this feature was introduced to participants during training, it was not used at all during the study. In the post-study interviews, participants said that they "*simply did not feel the need to use it*" [VP, S7]. They stated that "*the message was clear to them*" [VP, S10]. One participant stressed that when he needs to have an update about posts in folders he would usually navigate to the recent activity region [VP, S5].

9.4.2 Interaction with Navigational Enhancements

To assist VI users' navigation, three features were introduced: JAWS PlaceMarkers, a Chat messages keyboard shortcut, and changes in voice to indicate form controls. This section reports VI users' interactions with these enhancements.

JAWS PlaceMarkers: This feature was used to provide a quick and easy way to navigate to the interface's major components. Four VI participants preferred not to use the PlaceMarkers. Two VI users stated in the post-study interviews that from experience "*PlaceMarkers are displaced* *with dynamic webpages*" [VP, S3] and therefore they did not use them. The other two VI users [VP, S9] [VP, S12] stated that they did not use PlaceMarkers because they are simply not familiar with them. However the 10 VI participants who did used PlaceMarkers in the study described how they helped them during the task as they "*Made navigating to parts of the interface much easier"* [VP, S3]. One participant commented "*I have never used PlaceMarkers before but after today I will start using them. They are very useful. They take you to where you want to go on a webpage very quickly*" [VP, S5]. The participants who used this feature rated its usefulness at an average of 9 out of 10 (SD= 1) (Mode =10).

The use of PlaceMarkers is limited as they can become displaced in a webpage with dynamic content. Given that the ACSZ webpage contains multiple dynamic updates it was very likely that PlaceMarkers would be displaced as the page was updated. However only recent activity PlaceMarkers were displaced. , and they were usually displaced when a new chat message or new post was added (i.e. an update to the webpage). Therefore using PlaceMarkers to reach the recent activity region was the least used approach with an average of 0.4 times (SD= 0.95).

Audible chat messages keyboard command*:* The third feature was a keyboard command to hear chat messages. When a new chat message alert is heard, the user can employ this shortcut to hear the message instead of navigating to the team chat. Although six VI participants did not use this feature, eight VI participants chose to use it quite heavily with an average of 11 times (SD= 4) times per participant. In the post-study questionnaire, the participants who used it rated its usefulness as well above average 9.11 out of 10 (SD= 1.16) (Mode =10). In the semi-structured interviews, they highlighted its usefulness; in fact four participants suggested having "*more hotkeys to perform different actions in the interface*" [VP, S5]. We asked the participants who did not use the feature, the reasons they chose not to use it. Three participants [VP, S9, S12, 14] said that they did not feel the need to use it and they preferred navigating to the team chat modal dialogue form, while the other three participants [VP, S1, S4, S7] said that they simply forgot this feature was available.

Changes in voice to indicate form controls: The last JAWS screen reader setting introduced made changes to the JAWS speech and sound scheme. It was used to help VI participants identify components of the ACSZ interface easily; a female voice was assigned to buttons and a male voice was assigned to the text in text boxes. The participants' satisfaction level for this feature was the lowest of all features provided. The participants rated it 4.75 out of 10 (SD= 2.86) (Mode=7) in terms of its usefulness. Seven participants thought it was useful and rated it between 6 and 7. They explained that it *"can tell the user if they are in a text box or a button*" [VP, S2]. The other seven participants felt it was "*not useful at all and especially for experienced web users*" [VP, S5] and gave it a low rating in terms of usefulness. They added that "*it can be distracting sometimes*" [VP, S9].

9.4.3 Screen Reader Navigation

As we introduced the use of PlaceMarkers to navigate to the major components of the interface, and in order to understand their impact, we observed the approach used by VI participants to navigate to the major components. Three approaches were identified: navigation using the JAWS virtual cursor and JAWS keyboard shortcuts, using PlaceMarkers, and using the JAWS built-in search. It was observed that the approach used was highly dependent on the user's previous experience and the component itself, as user experience and proficiency in web navigation has a great influence on the approach a user would employ to reach a component in a webpage (WebAIM, 2014). VI users were not observed using heading navigation; in fact during the training it was observed that heading navigation is not well supported in the interface. They emphasized this in the post-study interview by mentioning "*a better use of headings is certainly needed*" [VP, S10]. "*It would be easier to reach these parts [referring to search tab and recent activity region], if only they have heading*" [VP, S5]. On improving the interface, one participant commented that "*it needs good use of heading*" [VP, S9]

Table 9.10 details the number of VI participants who used each strategy and the average number of times a VI participant used a strategy to reach one of the major four components including: the folders tab, search tab, team chat and recent activities region using the three identified approaches. It was observed that even though a participant would use a combination of strategies, one strategy would always be used more than the others. It was observed that a participant would use a maximum of two strategies to reach a component.

Navigating using PlaceMarkers was the most frequently used approach to access the folders tab. The difference in the frequencies with which VI participants used each approach to reach the folders tab was significant with the chi-square test ($\chi2=23.61$ and $p=0.00001$). Eight VI participants employed this approach in the co-located condition with an average of 3.12 accesses per study while six VI participants employed this approach in the distributed setting with an average of 4.16 accesses per study.

Navigation using PlaceMarkers was also a popular approach to reach the search engine. It was the second most-used approach with seven VI users employing it in the co-located condition with an average of 3.57 accesses per study, and nine VI users employing it in the distributed condition with an average of 5.55 accesses per study. To reach the search engine VI participants used cursor navigation the most. 11 participants employed this approach with an average of 6.09 accesses per study in the collocated setting; and 10 participants employed it with an average of 5.4 accesses per study in the distributed setting.

Nine VI participants employed cursor navigation to reach the team chat, with an average of 1.55 accesses per study. Cursor navigation only supported reaching the team chat button but not actually entering the team chat modal dialogue form, so it was only used from 1 to 2 times by these participants. The main approach to reach the team chat, as we advised participants during the training, was to use the JAWS built-in search function, as described in section 7.10.2. This approach was used by 14 participants with an average of 5.35 accesses per session. Table 9.10 summarises the usage of each approach.

		Co-located condition		Distributed condition	
		Number of participants	Average [SD]	Number of Participants	Average [SD]
Folders	**PlaceMarkers**	8	3.12 [2.23]	6	4.16 [2.78]
	JAWS search	2	1.5 [0.7]	1.0	1.0 [0.0]
	Cursor navigation	5	2 [1.73]	6	3.5 [2.81]
Search	**PlaceMarkers**	7	3.57 [1.51]	9	5.55 [2.6]
	JAWS search	3	1.33 [0.57]	-	-
	Cursor navigation	11	6.09 [3.04]	10	5.4 [3.62]
Team Chat	**PlaceMarkers**	2	2 [1.41]	3	3 [2.64]
	JAWS search	2	3 [1.0]	14	5.35 [2. 87]
	Cursor navigation	4	1.5 [0.57]	9	1.55 [0.72]
Recent Activity	**PlaceMarkers**	3	1.66 [1.15]	2	3 [0.0]
	JAWS search	2	1 [0.0]	1	8 [0.0]
	Cursor navigation	3	1.33 [0.57]	6	1.83 [1.6]

Table 9.10 Summary of number of times each screen reader navigation approach is employed.

9.5 Classifying the Errors Encountered

Error is an important measure of participants' interaction with the interface. Though the participants' satisfaction levels in terms of the interface's ease of use and accessibility are quite high, as seen in table 9.2, a numbers of errors were logged. We categorised the errors according to the nature of the error and its underlying cause into three categories: errors related to VI users' navigation in the interface; errors that have an underlying accessibility problem; and general errors which are encountered by both VI and sighted users and are mostly related to one or more errors in the interface or in the machine being used.

9.5.1 Errors Related to Navigation Using a Screen Reader

When interacting with different components in the interface a number of VI participants experienced times when they were either not sure where they were or unable to reach where they wanted to be. The incidents were mainly related to participants being unable to reach a certain major component or being unable to locate a specific interface feature; a total number of 11 incidents were recorded. In the co-located setting an average of 0.5 instances were recorded, and in the distributed setting an average of 0.28 instances were recorded.

1. Participants unable to reach a major component.

On rare occasions during the session a participant was unable to reach a specific component. In the co-located condition, two incidents were recorded where a participant was unable to reach the search tab; these incidents were experienced by the same participant. After adding a post and while in the folders tab the participant would search for the search edit box. The participant did not realise that he is not in the search tab until he navigated the whole page looking for the search tab. The participant then found the search tab link and clicked on it. Another participant was actually on the search tab but was unable to locate the search engine edit box. The participant then searched for the term ‘search’ in order to reach the search engine text box. A similar incident was recorded in the distributed setting where the participant was unable to reach a search tab. In the distributed condition one incident was recorded where the VI participant was unable to reach a specific folder using TAB key navigation. Therefore she searched for the folder using the JAWS virtual search.

2. Participants not sure where they were

Seven issues were recorded when a participant was not entirely sure where they were on the interface, so they would perform an action incorrectly. One participant was looking for JAWS PlaceMarkers while in a different webpage to where the markers were located. The participant was unaware that he was not in the search results page. Additionally, due to the fact that edit text boxes are not labelled, two participants were observed typing in the comments edit box in the home page instead of the Team Chat edit box. Both participants noticed they were typing on the wrong edit box after they had finished typing the message and navigated to the next button to send the message. The button to submit the chat message is titled 'send', while the button to submit the comment is titled 'share'. Three incidents were recorded where a VI participant typed the search term in the team chat edit box and only realised when using a cursor key to navigate to the send button. One VI participant typed a search term in the comments edit box in the home page, and realised that he was in the incorrect place when looking for the search button saw the submit button.

9.5.2 Errors with an Underlying Accessibility Problem

We also noted the number of times VI participants asked the observer for assistance, and we recorded the issues they faced. VI users requested assistance from the observer an average of 1.21 times in the distributed setting and an average of 0.78 times in the co-located setting. When the time spent resolving an accessibility issue was more than one minute, the other participant was asked to stop working. When the issue was resolved, both participants were asked to continue the task. This time was not included in the time spent performing the task. We categorized the issues that occurred as follows:

- Issues related to the unlabelled text fields in the add post form: Three calls for assistance by VI participants, one in the co-located condition and two in the distributed condition, were due to the fact that the add post form text fields are not labelled, hence the participant faced confusion when filling the form. In this case the observer advised them to find the title and the body text box. The average time to solve this issue was 00:46 seconds.

- Form feedback: When a field is missing the dialogue box shows a comment next to the missing field in red, which is not communicated to the user by the JAWS screen reader.

One participant encountered this issue in the distributed condition. The observer advised the participant in filling the required text fields. The process took around 01:40 minutes.

- Add post form navigation: This issue was reported in the accessibility review 7.6.5. The majority of VI participants noticed this issue in the training and were able to deal with it. However three VI participants, two in the co-located condition and one in the distributed condition, found it difficult to navigate through the dialogue box and were unable to perform the task and asked for help. They asked the observer for help when they noticed that the JAWS screen reader's forms mode commands were not working properly. The observer would then remind the user that JAWS is not in forms mode and ask them to use the cursor keys instead of the TAB key to navigate between the form controls. The average time spent in assisting the participants for this issue was 00:21 seconds.

We also recorded the number of incidents where VI participants failed to complete a certain task at the first attempt, and the number of attempts that were made after that before they succeeded in performing the task or asked the observer for assistance. This data is shown in table 9.11. An average of one incident per study was recorded in the distributed condition and an average of 0.21 incidents in the co-located condition. A total of 13 out of 17 issues were resolved by the participants without asking for assistance.

	Number of failed first attempts	**Number of attempts until they succeed or ask for assistance**
Accessing team chat	5	2.4, All participants were able to resolve the issue.
Returning back to the webpage while the dialogue box was still open	1	1, Participant called the observer for assistance to advice in form feedback issue.
Adding a post	3	0.33, All three participants called the observer for assistance for help in add post form navigation issue.
Saving a link to the folder	4	0.5, All participants were able to resolve the issue.
Creating a folder	3	1.6, All participants were able to resolve the issue.
Adding a link	1	0

Table 9.11 Summary of incidents where VI participants have failed to complete a certain task at the first attempt.

9.5.3 General Errors

A number of general errors were recorded by both VI and sighted participants that seem not to be related to an accessibility issue. Similar to the accessibility-related issues, when the time spent resolving an accessibility issue took more than one minute, participants were asked to stop work until the issue was resolved. This time was not included in the time spent performing the task. The following issues were encountered by VI participants:

1. Accidentally leaving the project home page and navigating to the dashboard home page: Four VI participants encountered this issue and asked the observer to help them in navigating back to the project home page. The observer guided them to the link for the project on the dashboard page. The observer help took on average 0:35 seconds.

2. Remembering specific instructions from the training session: VI participants requested help from the observer in reminding them about instructions from the training session. Three VI participants requested help in advising them on how to reach the team chat modal dialogue form. As explained in section 7.10.2, to reach the team chat participants were given specific instructions. Two participants asked for assistance in helping them with remembering the shortcut for place markers.

3. Other issues included:

Internet connectivity issues: Internet connectivity issues arose four times in the conducted studies where the observer had to intervene to solve the problem. On average it took 00:55 seconds to solve these problems. In one session the screen reader stopped responding, the VI participant had to exit the JAWS screen reader and restart it. For this issue the participants were asked to stop performing the task and resume once the application was restarted.

We also recorded the number of time sighted participants asked the observer for assistance along with the issues they faced. Sighted users requested assistance an average of 0.5 times in the distributed setting and an average of 0.5 times in the co-located setting. We categorized the issues as follows:

1. Internet connection issues: One sighted participant called for assistance in relation to internet connectivity. The issue required the observer to re-establish the internet connection which took about 00:43 seconds.

2. Technical issues related to the interface, included the following

    a) Unable to add a tag due to issues in the interface: after spending 00:40 seconds trying to add a tag, one sighted participant called for assistance for help, after which the observer restarted IE.

    b) Unable to type in the team chat, add a post in the dialogue box or add a link dialogue box. This issue was only raised by sighted users. The reason behind it seem to be a problem in the interface. One participant was unable to type into the team chat text box. This issue happened once for four sighted participants. The issue required the participants to restart IE, and it took an average of 00:37 seconds to resolve. Another participant was unable to type into the add post title text box. This issue happened once for one participant. To resolve this issue the participant restarted IE. The issue took 59 seconds to resolve. A participant was unable to type into the add link title text box. The participant restarted IE and it took 01:04 minutes to resolve.

3. Reminder about a feature: Two sighted participants asked the observer for help in reminding them about how to save a link into a folder.

4. While the add post dialogue box was open, the page moved upward and the user could not find the add post dialogue box. The participants asked for assistance and it took the

observer 2:12 minutes to resolve the issue. The issue occurred again later in the session but the participant was able to solve it, and the time lost was negligible.

9.6 Chapter Summary

This chapter's main contribution is providing an analysis of the user-focused interactions. It starts with investigating the IS behaviour in section 9.2. This is followed by an examination of the individual interaction patterns with the interface components and features in section 9.3. Section 9.4 discusses VI users' interactions with the interface accessibility enhancements. Finally section 9.5 describes the errors VI and sighted participants encountered when using ACSZ, and the time taken to resolve them. In the following chapter we present a thorough and consolidated discussion of the collaborative and individual interaction results of study 2 reported in chapters 8 and 9. We then introduce a set of evidence-based design suggestions toward the inclusive design of CIS systems.

Chapter 10 Study 2: Consolidated Discussion of Findings and Design Implications

10.1 Introduction

The two previous chapters presented a study that examined collaborative information seeking when using an extended CIS system (ACSZ). The interface provides a mechanism for users to store retrieved information, web links and comments in a shared workplace. The interface allows two level structuring by allowing users to create folders and store information in them. Users can see changes made by other collaborators in the shared workplace and are able to send instant messages to their collaborator via a chat messaging tool. Audio alerts of changes made and messages received were available for VI users. An overview of updates made to the shared work place was also made available by the interface.

The results presented in chapters 8 and 9 provide a detailed view of the participants' collaborative and individual interactions. They detailed the effect of a shared workplace on the awareness information made available by users. They described the ways in which labour was divided and how information was organized. They examined the users' interactions with the interface by highlighting the most used features by each group. They also discussed the VI user's navigation mechanisms, the effect of the introduced JAWS features on the use of the interface and discussed the accessibility issues encountered during the sessions.

In this chapter we synthesize the main findings reported in the two previous chapters, based on the two main perspectives identified in the research questions of the second study (section 8.3): the collaboration and the individual interactions with the interface. This chapter starts with a discussion related to the collaboration in section 10.2, the discussion consider study 1 as the bassline study. It discusses the results in the light of study 1, making direct comparisons where possible. The individual perspective, discussed in section 10.3, comprises the individual IS behaviour, the user interactions and the related usability and accessibility issues. In terms of the individual IS, and similar to the collaborative aspect, we consider the results of study 1 as our baseline study in which direct comparisons are made to highlight the impact of introducing a tool to support the process. The team and the individual aspects are inter-related and can't be looked at in isolation from one another. Both the team and individual aspects also influence the participants' task performance. The chapter then discusses the effects of using the ACSZ interface on the CCIS process in section 10.4. The Chapter concludes by proposing a set of design suggestions toward the inclusive design of CIS systems in section 10.5.

10.2 The Collaboration

This section starts by reviewing participants' task performance in section 10.2.1 using two different measures: how far each task has been completed by each collaborator and by the team, and how satisfied the team is with their performance. It compares the results of both conditions in both studies and highlights the impact of the ACSZ system on participants' performance. We then examine the two main dimensions of collaboration, the division of labour in section 10.2.2 and awareness in section 10.2.3.

10.2.1 Users' Task Performance

RQ1: Is the number of sub-tasks completed higher using ACSZ (study 2) than using software tools which users routinely employ in everyday tasks (study 1)?

To answer this question, we looked at differences in task completion between the two conditions of study 2 and compare the results with those of study 1. Similarly to study 1, pairs completed more sub-tasks in the co-located condition, yet the differences between the two conditions is not significant with t-test results at ($t(26) = 2.05$, $p=0.722$). Additionally, as in study 1, sighted participants performed a slightly higher number of sub-tasks in study 2, however the difference was only significant in the distributed condition at ($t(13) = 2.178$, $p= 0.04$).

When comparing the results between the two studies, there is an indication that both VI and sighted participants performed slightly better in study 2. In study 2 the average number of total sub-tasks completed by both VI and sighted participants was slightly higher than the average number of sub-tasks completed in study 1 in both conditions. However the differences between the results in the two studies was not significant at ($t(13) = 2.05$, $p=0.36$) in the co-located condition and ($t(13)= 2.05$, $p= 0.39$) in the distributed condition. Furthermore, when looking into the overlapping of sub-tasks, there was a slight improvement in the second study where the average number of occurrences was slightly smaller.

The number of sub-tasks completed together was slightly higher in study 1. Two factors were highlighted as the reason behind completing a sub-task together in section 5.5.3. One of these reasons is related to needing to look at search results together and collaboratively make sense of the retrieved information. The other reason was that some websites were inaccessible and it was impossible for the VI partner to complete the task individually. In study 2, there were no occurrences of participants completing a sub-task together in the distributed setting and only 1 occurrence in the co-located setting.

Finding 1- The interface has helped the participants to complete the tasks more efficiently. The shared workspace helps participants in collaboratively making sense of the data. This has had the effect of making the need to collaborate in order to complete a sub-task successfully quite rare.

We looked at the best and worst task performances in both studies in an attempt to highlight the reasons for such differences. Two pairs (S3 and S6) were in the top three best performances in both studies. S3 were colleagues; a manager and her personal assistant. Both mentioned in the post-study interviews that they are used to organizing trips, conferences, and looking for information on the web together. S6 comprised a VI Financial analyst and a sighted computer science PhD student who have never worked together previously. However the VI participant asserted that multi-tasking in her daily job and using a number of applications to organize retrieved information certainly helped her in performing the given tasks. Unlike the highest performing pairs, the three lowest performing pairs were different in each condition. This is excluding one pair [S14, VP, and SP] in the co-located condition in both studies and in the distributed condition in study 2, who performed relatively poorly. When looking at pairs that performed well and pairs that performed poorly in terms of task completion. There are number of reasons that might affect a team's performance while performing a CIS task. As identified in the previous chapter and as will be further discussed in this chapter, a number of factors contribute to this process, including, the interaction between the users, the interaction with the interface, and accessibility issues encountered.

Finding 2- There is no one single factor that determines how well a pair perform. It is usually a combination of factors including the pairs interactions with each other, the individual interactions with the interface, training and previous experience and computer literacy.

RQ2: Were the participants more satisfied with their performance in the search tasks using ACSZ (study 2) than using software tools which they routinely use in everyday tasks (study 1)?

Users were asked to rate how satisfied they were with their performance and with their communication levels in each task. In general, as reported in section 8.5.3, both VI and sighted participants were satisfied with the level to which they performed and with their communications during the sessions in both conditions in study 2. On average, sighted participants performance satisfaction ratings were higher in both settings, though the difference was only significant in the co-located setting at ($t(13)= 2.17$ $p=0.03$).

Comparing the results from study 1 and study 2, the users' satisfaction levels were much higher in study 2 using ACSZ at ($t(27)=2.06$ $p < 0.0001$) in the co-located setting and ($t(27) = 1.96$, $p= 0.06$) in the distributed setting. Participants expressed their satisfaction with the use of the system in the post-study interviews, aspect such as the integration of instant messaging with a shared workspace to share information with collaborators, an integrated search engine and being able to see collaborators progress updates were highlighted as making the process easier from their point of view. As reported in section 9.3 in the post-study interviews, participants expressed that performing the search task using ACSZ is "*easier*" [SP, S6] and "*very practica*l" [VP, S8]. VI users added that the integrated system avoided them the inconvenience of switching from one application to another in order to complete a certain sub-task. In fact, this was evident when the time spent switching from one application to another was calculated. The average time spent switching from one application to another was higher in study 1 (01:45 minutes, SD= 0:19) in the co-located condition and (01:21 minutes, SD= 0:34) in the distributed condition, than (30 seconds, SD= 0:33) in the co-located condition and (29 seconds, SD= 0:23) in the distributed condition.

Finding 3- Participants were more satisfied with their performance undertaking CIS tasks using the ACSZ interface, even though this was fairly new to them, than when using software tools which they routinely use in everyday tasks.

10.2.2 Division of Labour

RQ3: Did participants divide the labour differently when using ACSZ (study 2) than using software tools which they routinely use in everyday tasks (study 1) and what was the nature of any such differences?

As seen in the results section in 8.5.1 of study 2 stage 3, in which the pair would review and discussed the division of labour after completing a sub-task, occurred very few times in the distributed setting. The reason it occurred so infrequently in the distributed condition could have been due to the fact that the cost of communication is higher in the distributed setting where participants did not discuss verbally. For example, one participant commented:

> "*Here [in the co-located condition] it was kind of a less expensive to engage with my search partner, as in the distributed situation I had to go and type a chat message. But in here we exchanged a lot more information verbally, even if we didn't need it*" [SP, S1].

Stage 3 did not occur at all in the distributed sessions of study 1, in which the cost of communication was even higher as participants had to switch from one application (browser or note taking tool) to an (email or instant messaging tool) to discuss with their partner. Additionally, of course, there was no explicit mechanism to support awareness concerning the CIS process in study 1.

Finding 4- The occurrences of stage 3 in study 2 in the distributed setting indicate that providing appropriate awareness information and an integrated communication tool gives participants a better chance to review task status and collaborate. In study 1 participants had to put more effort into providing workplace and group awareness information, and in working on the task, thus they were able to give less time to reviewing and managing the task.

In terms of strategies employed to divide labour between pairs, it was observed that in the co-located setting, pairs usually tended to employ the 'divide and conquer' strategy (Morris, 2008), working closely together by discussing the search results, the information stored and the organization of sub-tasks. In the distributed setting, this discussion was less common. Participants were observed working more independently and only updating each other about their progress, a strategy which Morris (2008) refers to as a 'brute force' strategy. This is in agreement with results from study 1, section 5.5.2. From looking at the results reported from study 2 in section 8.5.4 and study 1 in section 5.5.2 clearly there are certain factors that affected the decisions made when dividing labour. The factors that seem to affect the decisions are:

1. The condition (co-located/distributed) and the awareness information

As discussed, in both conditions the level of collaborative activity had a great influence on how labour was divided. This has also had its effect on awareness information exchanged and the use of that information. From both studies 1 and 2, it can be deduced that each strategy used influenced the percentages of the types of information exchanged. For instance, in the distributed condition, the amount of critical information exchanged was lower as the pairs were working more independently, sub-tasks were performed almost separately and rarely involved any sort of discussion or even an update of progress. Moreover, it was observed that the information made available by partners to avoid duplication of effort was much higher in the distributed condition.

2. Web accessibility and user experience

As reported in the results of study 1 in section 5.5.2 and study 2 in section 8.5.4, the decisions made concerning the division of labour were highly dependent on the VI participant's experience of how accessible the websites they would be visiting were likely to be. As some sub-tasks may contain inaccessible web forms that may cause a delay or affect the completion of the task. Therefore, the majority of the VI participants preferred to avoid such tasks.

Finding 5 - Dividing the labour in such a way that allows VI users to avoid accessibility issues that they may come across has positive effects on group performance by enabling the completion of more tasks in less time and reducing wasted effort.

10.2.3 Awareness

RQ4: What is the impact of the awareness mechanisms made available by ACSZ on the information exchanged by users to provide awareness information to their partners?

ACSZ provides awareness information through a number of features, as detailed in 7.8.3. These features provide both workspace and group awareness. When comparing the results of study 2 with the results from study 1, it can be deduced that the existence of the shared workspace and awareness features affected both the volume and type of information explicitly exchange by collaborators either verbally (in the co-located condition) or in written form (in the distributed condition).

Firstly, in terms of the information exchanged, the average amount of information exchanged is much lower in study 2 than the average amount of information exchanged in study 1. In fact, the difference between the two studies is statistically significant with chi-square test giving ($\chi 2$= 42.22, $p < 0.0001$) in the co-located setting and ($\chi 2$= 4.98, p=0.02) in the distributed setting. In study1, participants would supply or request information to avoid duplication of effort and to find out the progress of their partners. The awareness related features make this information about the collaborators activities readily available, therefore the average amount of supplied and requested information is much lower in study 2.

Additionally, the availability of awareness information has affected the time spent using the communication tool in the distributed condition. The chat tool in study 1 was the only tool to facilitate awareness information in the distributed condition. In study 2 the time spent using team chat is much less than the time spent using a chat tool in study 1. The difference between the time spent using the communication tool is statistically significant with sighted participants at ($t(25)= 3.16$ and $p=0.0041$). On average VI participants used the communication tool less in study 2; the difference was not significant at ($t(25)=1.4458$ and $p=0.16$). In study 1, the pairs used the communication tool to provide each other with awareness information about their progress as well as sharing the retrieved search results in the absence of a shared workspace. In study 2, it is apparent that collaborators put less effort into communicating awareness information as the tool provides awareness mechanisms. This agrees with findings from a previous study by Shah (2013a) in which they showed that as workspace and group awareness information become available in an interface in a distributed condition, participants make less "coordination effort" in reporting their actions. They define "coordination effort" as the number of coordination messages exchanged throughout the CIS activity and the time spent reporting these messages. It is significant that this finding from CIS appears to transfer into a cross-modal context. Moreover, in our study, this finding is also valid in the co-located condition.

Finding 6- In study 2 the ACSZ tool provided awareness information to the collaborators through its features. Hence, in study 2 participants needed to communicate less awareness information (expending less coordination effort) to their partners which helped them to engage in the task and improve team performance.

It was observed that in study 2, the information supplied or requested by participants maybe of two types; concerning group awareness or workspace awareness. The former type did not appear in study 1, since there was no shared workspace. Yet the frequency of its appearance in study 2 was minimal. Furthermore, in study 2 the amount of information related to group awareness was significantly higher, as described in the results section 8.5.5. In fact, the occurrences of requested information about workspace awareness were minimal in the co-located setting and there were no occurrences at all in the distributed setting. As described in the interface features section 7.8.3 ACSZ provided a lot of information regarding workspace awareness, but very little regarding group awareness (i.e. Query terms being entered and websites being explored). This could be a reason that influence the participants to provide more information about their progress to facilitate group awareness and less information about the organization and management of information to facilitate workspace awareness.

Finding 7- Awareness information made available by the ACSZ interface had an influence on the type of awareness information supplied or requested by collaborators.

The information supplied and requested is further classified into three forms; information about the action just started, information about the action currently being worked on, and information about an action that has been completed at a given time. The majority of information supplied and requested to provide group awareness was related to current actions. The majority of information supplied and requested relating to provide workspace awareness was about completed actions. Even though this information is made available by interface features, a number of participants preferred to communicate it verbally in the co-located setting. This pattern of behaviour did not occur at all in the distributed setting, as participants were highly dependent on the information made available by the ACSZ interface. They would either check the folders created and post in them or view the recent activity panel.

Finding 8- Using ACSZ the participants provided and requested more group awareness information about their current actions and more workspace awareness information about completed actions.

RQ5: How do the users employ the information received? And does it have an effect on the amount of the task completed (participants' task performance) as in study 1?

We now look into the usage of information received. As in study 1 this can be classified into four categories; information not needed for the current sub-task (category A), information needed but not critical to the current sub-task (category B), information critical to the current sub-task (category C) and information needed to avoid duplication of effort (category D). In study 2 the proportion of information received but considered not relevant for the current sub-task was relatively low in both conditions. The difference between the two conditions is more apparent in the proportion of information that is critical to the current sub-task and information to avoid duplication of effort. The first one is considerably higher in the co-located condition, as the labour is divided in such a way that the sub-tasks are more dependent on each other and thus the information supplied is classified as critical. The information to avoid duplication of effort is higher in the distributed setting, as the participants worked remotely they naturally sought assurance that their partners are not working on the same sub-task. This agrees with the results from study 1.

Finding 9 - The condition (co-located/distributed) can influence the type of information exchanged. This agrees with study 1 (Al-Thani et al, 2013) in which it was highlighted that the type of information exchanged depends on the way the task is divided and the setting of the CIS activity.

The proportion of information needed but not critical to the current sub-task is always higher in the pairs that performed well in both conditions and in both studies. Pairs who performed well tend to be more engaged in the process and provided each other with updates about their progress, even though sometimes the information they provided was not needed. This agrees with a previous finding that a continuous supply of group awareness information can increase collaboration efficiency (Al-Thani et al., 2013; Shah, 2013a).

Finding 10- The continuous supply of group awareness information that is needed but not critical allows participants to know more about their team members' activities and hence helps them in being more effectively engaged and aware.

In study 2 the exchange of critical information has the highest proportion in the pairs with highest performance in the co-located condition, but not the pairs with highest performance in the distributed condition. This was not the case in study 1 where the results showed that the less the amount of critical information exchanged the higher the performance. This indicates an interface effect on the purpose of information exchanged. The availability of both a shared workspace and group and workspace awareness mechanisms had an impact on the type of information exchanged and the purpose behind the exchange. This is shown in the differences between the results from both studies. When looking into the studies where partners' performance is relatively low in the distributed condition in study 1, unlike the results from Study 2 the amount of information exchange to avoid duplication is the lowest. In study 2 participants were also notifying one another about the changes they made in the shared workplace, which made the amount of information to avoid duplication the highest.

Other than exchanging information to facilitate awareness, it was observed that participants also used the interface features to check their partner's search progress and updates made in the shared workspace. This type of behaviour usually occurred after completing a sub-task and before starting another sub-task. Participants used the past search feature to find out the search queries entered by their partners. As reported in section 9.3.4 this feature was only used in the distributed setting in three sessions. To check updates made in the shared workspace participants would either navigate to folders or check posts added by their partners or they would navigate to the recent activity region and go through the activities completed by their partners.

While navigating to folders was used more by sighted users, checking recent activity was more preferred by VI users. According to the post-study interview results in section 9.3.1 there are two reasons that could have led to VI users preferring to check the recent activity region over actually checking the folders. Firstly it is easier and quicker to navigate to as it is always available in the ACSZ interface. Secondly and most importantly it provides an overview of all the activities that have taken place in the project.

Finding 11- The introduction of a tool that support CCIS influenced the type, volume and use of awareness information. It also influenced users' actions in improving their own awareness by using the available features.

10.3 The Individual

10.3.1 Stages of IS

RQ 6: What are the effects of the use of ACSZ on IS behaviour?

Most of the stages of IS were performed individually using ACSZ except for the information management stage in which evidence of collaboration was observed. To answer RQ6 we examine the different stages of IS we identify the differences between VI and sighted users and compare the results with study 1. A number of differences between the studies were observed which suggests the influence of the ACSZ interface. In this section we discuss these differences. These mainly concern the number of search results viewed, and the amount of collaboration observed during the stages of IS, in particular the results exploration and the organisation and management of retrieved information stages.

In terms of search results viewed by VI and sighted participants, there are certainly differences between them compared to those reported in study 1. The reason behind this difference might be due to the serial nature of screen reader output as discussed in 5.5.9. However in study 2 the average number of search results explored by both sighted and VI participants was smaller in both conditions than in study 1, as shown in table 10.1. Similarly participants spent less time browsing websites in study 2 than in study 1 as shown in table 10.2. In fact the difference in the time spent browsing web sites by VI participants in study 2 was statistically significant across

the 2 conditions.

		Study 1	Study 2	Paired t-test results
Co-located condition	**VI participant**	14:29 [08:48]	07:45 [03:32]	(t(13)= 5.77, p= 0.0001)
	Sighted participant	14:19 [08:47]	11:05 [05:19]	(t(13)= 1.97, p=0.07)
Distributed condition	**VI participant**	10:44 [06:47]	07:45 [03:34]	(t(13)= 2.4, p=0.031)
	Sighted participant	11:49 [06:08]	10:45 [05:18]	(t(13)=1.8, p=0.09)

Table 10.1Comparison between time spent browsing websites in studies 1 and 2 in minutes. (Average [SD]).

Two reasons seem likely to be behind this difference in behaviour. Firstly the way the ACSZ interface influences search behaviour and secondly the existence of a shared workplace that encourages participants to spend more time interacting with the interface than exploring search results. In ACSZ when a user clicks on a search result, it opens in a new window. After browsing a website and finding the required information, the user needs to return to the ACSZ window and store the required information using the interface features. As reported in section 9.2.1 it was clear this process affected the IS behaviour of both VI and sighted participants, in that they preferred not to leave the ACSZ interface and use the ‘save link’ feature without actually accessing the website. In fact three VI participants did not browse any website results in both conditions and one sighted participant only browsed websites in the co-located condition. As reported in section 9.3.1 in the post-study interviews participants mentioned the fact that ACSZ opens a new window when showing a web result was quite confusing. However this is likely to be less of an issue in real contexts of use as users would be more familiar with the interface and would know their time is not bounded, and hence there may be less stress on them in completing the task.

Finding 12- The ACSZ interface has clearly influenced users behaviour, as the average number of websites viewed and time consumed browsing websites is less in study 2.

The second factor that may have affected the number of results viewed by each pair is the fact that in study 2 participants are interacting with a shared workplace. The time spent managing the retrieved information in study 2 is longer in comparison to the time spent managing the retrieved information in study 1. In study 1 users store information without sharing it; information is stored by each individual separately typically in the form of notes in a word processing document, a notepad application document, or a piece of paper. In study 2 the participants needed to create a structure (folders) into which retrieved information can be saved, and then having retrieved information they had to create posts and/or save links. Both VI and sighted participants in both condition spent a longer time in study 2 than in study 1 on the process of organising and saving retrieved information.

Unlike study 1, there was no evidence that collaboration occurred in the results exploration stage in study 2. In study 1 VI participants ask their sighted partners either to collaboratively explore search results for the pair to make sense of information together, or as an assistant to review the information more efficiently. It can be deduced that one reason that may be behind the disappearance of this behaviour in study 2 is the way ACSZ is designed. ACSZ has features that allows collaborators to see the search results of their team members, and hence this is likely to reduce VI participants' requests for assistance from their sighted partner in viewing search results. Sighted partners can simply click on the search query terms listed in the past searches drop down list and view the search results of their partners and discuss it with them. Two VI and one sighted participant looked at the results of searches conducted by their partner in order to discuss and make sense of information found. They were not actually performing the task together but collaborating to make sense of the retrieved information. Participants who used this feature commented, "*It made it easy when informing my partner about websites that are important to the task*" [SP, V8].

Finding 13- Having the ability to view team members search results influenced the ability of the participants to collaboratively make sense of retrieved information.

Another possible reason that might have influenced the disappearance of this behaviour is that VI users might have felt that because it is a CIS system, they ought to perform all stages of the IS process on their own.

The only stage that was performed collaboratively in study 2 is the management of retrieved search results. The presence of a shared workspace has clearly encouraged participants to perform search results management collaboratively. While in study 1 there was some evidence that collaborative behaviour happened in more than one stage of IS, in study 2 collaboration only occurred in relation to results management. In fact, the time spent in managing information in study 2 was much longer than the time spent managing information in study 1. In study 2 the participants have a shared space to manage information in which they spent effort and time in organizing the information. While in study 1 the retrieved information is merely stored in a document or exchanged via chat messages or emails. Thus, the time spent using communication tools is much less in study 2 than in study 1.

In the task specification participants were asked to work together, they were not explicitly asked to form a common outcome but in study 2 all pairs discussed and worked together to form a shared result. Thus after study 2 they are left with a common outcome that consists of a set of shared results structured in a way with which they are both familiar, and a clearer understanding, through the availability of the awareness information of what their partner has found. It could be argued that the result of the CCIS process in study 2 was much better than that of study 1, as there is a properly shared body of information. Because it has been properly structured, the information is much more findable and usable. By contrast, after the session in study 1 partners are left with separate sets of results, sometimes in different media, differently structured, and with very little shared information. In fact, only three pairs of participants produced a common outcome in the co-located condition of study 1, and no pairs produced a shared common set of results in the distributed condition. Taking a team perspective the results of the sessions of study 2 are greatly to be preferred to those of study 1, as both team members have access to all the results of the CIS process. In contrast, there is nothing in the process in study 1 to ensure equal sharing of the results within an agreed common structure.

Finding 14- The interface has encouraged participants to create a shared structure containing the results of the CIS process, with equal access by both team members to the results set. Furthermore the awareness mechanisms of ACSZ and the ability to access partner's previous search activities make it more likely team members will know how far their partners progressed in the CIS process and will have had the opportunity to examine results retrieved by their partner.

RQ 7: How do the participants organize and manage retrieved search results in the shared workspace and make use of the interface features?

While the previous question RQ6 looked into evidence of the ACSZ system's effect on the stages of IS, this question explores approaches employed in the only stage which was performed collaboratively. The participants employed a number of approaches as well as interface features to organize and manage retrieved search results. A common observation in both studies is that VI participant spent slightly more time on this activity than their sighted partners. The difference was not statistically significant in either setting as shown in section 9.2.2. This slight difference may be due to the serial nature of screen readers and to some accessibility form navigation issues that the VI participants faced when adding posts to folders, as discussed in section 9.3.2.

In terms of approaches employed to structure retrieved information, the literature has long identified that there are apparent differences between people in their approaches to the organization of information. Malone (1983) classified users into 'filers' of information: organization is well-structured and 'pilers' of information: organization has no structure and tends to be messy. More recent studies on e-documents (Bruce et al. 2004) and web bookmarks (Boardman and Sasse, 2004) confirms similar results. The main purpose of organizing information is to help users to return to them when needed in a reasonable time and ease (Bruce et al. 2004). In a collaborative context, where there is a shared workspace, this applies to all team members being able to come back and easily use information. Both study 1 and 2 attempt to classify users on a similar scale.

In study 2 ACSZ enforced a certain approach to structuring information which consisted of creating folders and storing retrieved information in them. As described in the results section 9.3.3 even though the interface provides a certain approach for storing information, a number of different information organisation behaviours were exhibited. It was observed that once a participant developed a strategy for storing information that participant would keep using the same strategy for each new piece of information found and probably would repeat the same pattern in the next condition. Previous research has identified (Jones, 2007) that even though people may change strategies for organising information over time they usually stick to a single strategy in a session. In terms of structuring information retrieved the majority of participants 10 pairs (20 participants) as reported in 9.3.3, created a folder for each category of information while only 3 pairs preferred to store all the retrieved information in one folder. This was not the case in study 1 where having a structure for the retrieved information rarely occurred. In study 1 very few participants have actually structured the information they retrieved. A total of 7 out of 28 participants in the co-located condition and 5 out of 28 participants in the distributed condition have structured the information they found. By structure we mean creating sub-headings with details under them rather than simply listing the retrieved information.

Finding 15- The design of the interface led to a more structured approach to organizing information retrieved, although within this overall approach, a number of individual variations were still observed.

In study 2 the interface provided quite a straightforward approach for users to store information in which users create folders and store information in those folders using features such as add a post or save a link. The most common approach used for organising stored information in study 2 was the one influenced by the interface which basically consisted of creating a folder and storing each piece of retrieved information using one feature. This approach was used the most by VI users; 13 VI users and six sighted users were observed using it. However we observed participants employing interface features in a variety of ways as reported in section 9.3.3. The differences between the strategies used to store information by VI and sighted participants was statistically significant with chi-square ($\chi2= 8.37$, $p= 0.01$) in the distributed setting and ($\chi2=10.12$, $p= 0.006$) in the co-located setting.

The majority of VI users used one feature to store one piece of information. It can be inferred that the majority of VI users preferred this strategy for two reasons. Firstly the serial nature of screen readers has an effect of slowing down users' performance. Hence in order for VI partners to be efficient in looking for information they would tend to use only one feature to store the information retrieved, particularly if that method involved few steps, which saving a link did. Secondly the issues reported using add post from the training sessions had a major effect in making this feature less popular. As discussed in section 9.3.2 VI participants express that using ACSZ was "*pretty straightforward except when creating a new post*" [VP, S14].

The second most popular approach, used only by sighted participants, was to use two features to store one piece of retrieved information. Using this strategy the user would first save a website link and then add a post that contained specific details from the website. This strategy was always likely to appeal much less to VI participants due to the extra time it would take them for relatively little gain.

The third pattern of behaviour observed is when a user would use two features but in a three level hierarchy, as described in section 9.3.3. This type of behaviour occurred the most with sighted participants, as it also required more effort to store information. However it was also observed being employed by one VI user [VP, S2], who was particularly proficient at using his screen reader on the web and showed particular enthusiasm when using the interface.

Finding 16- VI and sighted Participants differed in the ways they stored information. It can be deduced that accessibility of a component and the work load associated with a particular storage strategy can affect the VI user's choice of approach.

10.3.2 Training

The interface was new and rather unfamiliar to participants and the amount of training was inevitably constrained to fit in with participants' availability. The training sessions took place just before the study and included the features being demonstrated by the observer and also being tried by the participants, as described in the training procedure section 8.4.5. The training time was limited by the fact that the overall time duration for a given individual taking part in study 2 was limited to a maximum of two hours. This time was made up of two 35 minutes search tasks, followed by a questionnaire to answer and a post-study interview which together took about 15 to 20 minutes. Thus the dedicated training time was about 30 to 35 minutes. The total time (2 hours) required of participants to take part in study 2 was an inevitable compromise between providing adequate times for task performance, training and post-study data collection, vs. what seemed a reasonable time to ask participants to commit, particularly given the difficulties of recruiting adequate numbers of VI users.

Despite trying to cover all essential features, it was clear the participants' performance was not as good as it could have been if there had been more time for training. As reported in the results in section 9.5.3 a number of incidents were recorded in which both VI and sighted participants asked the observer to remind them about features in the interface. The number of times these incidents occurred is low but nevertheless a longer training time would have been of benefit. VI participants in particular would certainly benefit from additional time to be fully able to tackle the use of some features such as add post. This was stressed by the participants in the post-study interviews reported in section 9.3.

The potential of benefiting from additional training was further shown in the results reported in section 9.5.1. There were a number of times when VI participants were unable to identify where they were in the page. Even though PlaceMarkers were intended to help VI participants in navigation. Similarly a small number of incidents occurred where a VI user was unable to reach a specific component. In these situations the participants would either search for the specific component using the JAWS built-in search option, or would simply navigate the whole webpage again in an attempt to find the component. Facing these issues during the study led many VI participants to stress the importance of needing to use the interface more often to become familiar with its structure. The fact that sound is a temporal medium and that all VI participants in this study used speech-based screen readers means that compared to their sighted counterparts, VI users are not presented with an ongoing image of the screen they are working with. This is likely to indicate that more training is required to enable VI users to commit more of the interface structure to memory. The clarity of structure can help screen readers' users to navigate or locate required information more efficiently (Carey and Stringer, 2000). Given these difficulties the results obtained in study 2 are likely to represent an underestimate of what could be achieved in terms of task performance if participants had received more in depth training before undertaking the tasks.

Finding 17- All participants need time to familiarize themselves with the structure of a website. VI participants are likely to need more time because of the lack of a permanent representation of the interface with which they are interacting.

10.3.3 User Interaction

RQ8: Are the participants satisfied with the overall user experience?

Providing an interface that integrates a shared workplace a search engine and communication tool certainly had a positive effect on both the participants' performance and levels of satisfaction. As ACSZ provided an integrated solution both VI and sighted participants in study 2 spent significantly less time switching from one application to another. Table 10.2 shows the scores of a related t-test for time spent switching between applications by participants in each setting in both study 1 and study 2. For instance in the distributed setting in study 1 VI participants had to switch between four applications: the web Browser, the note taking tool, the document processing application, and the email client, while in study 2 participants had only to switch between two tools, the browser and the document processing application (in which the collaborative search task is stored). Moreover, the majority of users indicated in the post-study interview that an integrated solution certainly made the process of CIS easier as described in section 9.3.

	Co-located setting	**Distributed setting**
Sighted participants	t(25)= 4.08 and p=0.0004	t(25)=5.09 and p=0.0030
VI participants	t(25)= 1.3960 and p=0.1750	t(25)=4.58 and p=0.0001

Table 10.2 Comparison between time spent switching from one application to another in studies 1 and 2 in minutes.

Finding 18- An integrated system reduced the time and effort spent in switching between applications and so is likely to have a positive effect on the user experience and reduce cognitive load during the task.

RQ 9: How do users interact with ACSZ components and features?

Regarding use of the system all participants believed that using ACSZ had merit over the ad hoc tools used in study 1 rating its usability fairly high. Moreover as described in section 9.5 very few errors were recorded and the time spent resolving these errors is an average of 00:23 seconds in co-located conditions and 00:20 seconds in the distributed condition for VI users. When looking into participants' interactions with different interface components and features, it can be deduced from the results that the popularity of specific features or major components was highly dependent on three main factors:

1. The importance of the feature or the component.

As the task is search oriented the most accessed component is the search engine in the co-located setting. However it came second in the distributed setting with team chat being the most accessed component. Even though VI participants described the process of reaching the team chat as quite complicated, the need and importance of using it meant they were prepared to put in the effort required to reach it.

2. The ease of use

The ease of use played an important role in which feature participants used to store retrieved information. The add post feature allowed participants to enter a title and other information that might be required including a web-link, a file or a photo. However the most used feature for storing information was save a link which doesn't allow the user to enter any associated details. Even though Save link was the most frequently used feature by both the VI and sighted participants, as shown in the results section 9.3.2, there was a difference between the numbers of times VI and sighted participants used this feature. However there seem not to be any accessibility or usability issues behind this. The most obvious reason is that sighted participants performed on average more sub-tasks than their VI partners and hence save more web-links. However the underlying issue behind the difference in task completion remains the serial nature of speech in screen readers which is likely to slow down participants' interaction with interfaces in general.

Finding 19- The usability of a certain feature can determine its frequency of use.

3. The navigation effort required to reach a component or feature (discussed here specifically for VI participants)

VI users tended to use a sequential navigation strategy. Using this strategy the screen reader users let the software continuously read through the content of the webpage, or use the down arrow key to sequentially access all components on the page. This strategy is not common among screen reader users with an advanced proficiency. From direct observations and responses in the post-study interview it seems that VI participants have adopted this strategy for two reasons. Firstly they are more likely to use this strategy if they are not very familiar with the interface being used. It is part of the process of learning the interface, although it is time consuming because the user navigates through each component in the page. Secondly the fact that header navigation was poorly supported in the ACSZ system, as described in 9.4.3. An aspect over which we had no control, not being able to edit the HTML of the system.

10.3.4 VI Users' Interactions

Despite being an interface which was not originally designed according to accessibility standards, as reported there were very few issues recorded and the time spent resolving these was very limited and did not affect either the process or the performance of the participants significantly. The previous section looked into the user interaction in general and highlighted differences between VI and sighted users. In this section we examine VI users' interactions with the interface and in particular in relation to the enhancements we made to the interface.

RQ10: How did VI users interact with the awareness and navigation enhancements made?

There were a number of enhancements made, as described in section 7.10, these enhancements were intended to support awareness and navigation. To support awareness the JAWS script provides VI users with audio alerts when a new message arrives or when an update happens to the shared workspace. To support navigation JAWS PlaceMarkers were employed to help users to navigate different components. An audible chat message keyboard shortcut command was introduced to allow users to hear chat messages instead of navigating to the team chat dialogue window. A change of JAWS voice was employed to assist participants to identify unlabelled objects.

The most popular and well received features were the shortcut keys to hear the chat messages, the PlaceMarkers and the new message chat alerts. In terms of awareness enhancements two notification alerts were available, however the participants felt more satisfied with the new message alert than with the new post alert. In terms of navigation enhancements the keyboard command for users to hear the chat messages allowed VI participants to quickly access the chat message and avoid tedious navigation to reach the team chat component. The perceived value of PlaceMarkers was highly dependent on the users' previous experience of these, as the consistency of PlaceMarkers varies depending on how dynamic the web content is, so users' expectations of these depended on whether they had previously used place markers with dynamic content. Therefore there were differences in the average number of times PlaceMarkers were used to access each component. The PlaceMarkers for team chat and recent activities tended to get displaced and so the average number of times they were used was much lower than the average number of times place markers were used to access the folders or the search engine. Even though PlaceMarkers had the displacement issue, participants found them very useful as a mechanism to speed up navigation and save time while performing the task. In fact, their satisfaction level was very high (8.57 out of 10).

Finding 20- Hot keys were important in allowing VI users to perform certain tasks more efficiently.

Finding 21- PlaceMarkers improved VI user's experience and presented an alternative easy way to reach the major components of the interface.

Even though mechanisms such as PlaceMarkers and audio chat messages were employed in key areas of the ACSZ interface to assist navigation and provide awareness information, it was observed that users still encountered some difficulties during navigation. The effects of these difficulties were apparent in different situations. VI users preferred using save link rather than the add post mechanism to save information. As highlighted in section 9.3.2 VI users encountered form navigation issues when filling the add post form (the other means of storing information). The other situation that affected the use of the add post feature is that the user is required to navigate to a folder and then add a post from there. Therefore the easier option to store search results was save a link. Moreover the majority of VI users preferred checking the recent activities region to find out about their partners' activities instead of navigating to each folder and checking the new posts from there. In fact the recent activities region was highlighted by the majority of participants as one of the most useful features in the interface. This strategy avoided wasting time navigating between folders and allowed users to have an overview of the information stored in folders and gave them the option to access posts from there. Thus the number of times folders were accessed by VI participants is significantly lower than the number of times they were accessed by sighted participants, at ($t(26)= 2.66$, $p=0.01$) in the co-located condition. There were no accessibility issues for VI users in accessing the folders. The difference may be due to two reasons. Firstly the serial nature of speech in screen readers that can generally slow down the whole process of navigation and interacting with the webpage interface. Secondly the fact that VI participants preferred viewing the recent activity region more often than their sighted partners, and so got the awareness and overview information they needed from there without needing to navigate between individual folders.

Finding 22- VI users experienced issues when attempting to reach certain components or features due to the fact that ACSZ is based on the SearchTeam website which was designed with only sighted users in mind. Interface components are strategically placed at specific parts of the screen to draw the visual attention of users.

Finding 23- VI users greatly benefited from the overview of recent activities provided by the interface as it was straightforward to access this component.

10.4 Effects of the ACSZ Interface on CCIS Behaviour

As discussed in findings 7, 12 and 19 in the previous section the ACSZ interface influenced both collaborative and individual interactions. Before discussing design guidelines that are likely to support the CCIS process this section discusses a number of issues linked to the current design of ACSZ and their apparent effects on the CCIS process. The effects are however certainly not limited to those identified below. From comparing with the results obtained in study 1 it appears to us that changes made in these areas can have an effect on the users CIS behaviour.

10.4.1 Awareness Information Made Available by Users

Awareness is a central issue in CSCW and CIS therefore looking into ways the interface has affected the type and amount of information exchanged to facilitate awareness was one of the aspects that the research questions in study two have examined. Finding 7 of this study revealed that the largest proportion of information exchanged by participants was information related to the progress of the IS process. Moreover the participants rarely exchanged information related to the organization and management of information retrieved. The way in which the ACSZ interface was designed probably influence this behaviour to some extent as the majority of information made available by the interface is related to the management and organization of information retrieved. Therefore less of it needed to be exchanged explicitly by the participants.

10.4.2 IS Behaviour

A noticeable difference between study 1 and two was the amount of time spent browsing webpages and the number of webpages browsed (Finding 12). The average number of webpages browsed by VI and sighted participants in study 2 was much lower than the average number of webpages browsed in study 1. There might be a design related issue behind this alteration in behaviour, as many participants mention in the post-study interview that having the web search results opening in a new IE window was quite uncomfortable and had added to the workload of moving from one IE window to another. They suggested that having the web search results open in an inner frame within the ACSZ window would allow them to explore results in-line more easily.

10.4.3 User's Interactions

When building an interface to be interacted with using different access tools, accessibility becomes a fundamental design consideration. SearchTeam was not designed with accessibility in mind, and therefore had a number of issues. In ACSZ, which is a relatively accessible version of SearchTeam, we attempted to improve accessibility. However due to the fact we didn't have access to the source code some accessibility issues remained unsolved, thus VI participants encountered these during their interactions with the ACSZ system. The design of the ACSZ interface affected both the VI and sighted users' interactions. In terms of VI users' interactions the add post form navigation issue resulted in a significantly low usage by VI users of this feature as reported in finding 19.

Apart from accessibility issues the interface had one apparent design issue that was reported by (10 sighted participants) in the post-study interviews. This was the issue that the interface did not provide an audio alert when a new message was received. This issue affected the number of times and the timing with which the sighted participants checked the received chat messages.

While the VI user had an audio alert notification provided by the JAWS Script, the GUI does not provide any audio notification. The interface also has no visual notification to the user when a message has arrived. Therefore usually when a chat message is received, a sighted user will notice it if and when they check the team chat dialogue window. This can certainly affect the interaction and the collaborative process.

10.5 Design Suggestions Toward the Inclusive Design of CIS systems

The following design implications were compiled throughout the analysis and discussion of the results obtained in study 2. This section starts by discussing the design suggestions related to CCIS. This is followed by design suggestions related to employing a mainstream CIS in a cross-modal context. It is important to assert here that in the study conducted, we employed one particular system and we make suggestions based on the evidence we obtained using that system. Thus, the set of design suggestions are not comprehensive as they do not cover all aspects of the CCIS process. However we highlight their importance in supporting the process of CCIS and their relevance to the use of a "mainstream" CIS system in a cross-modal context.

10.5.1 Improving Cross-modal Collaborative Information Seeking

The findings from study 2 have led us to introduce design suggestions that we believe are important to consider when designing a CCIS interface. Moreover the ACSZ system supported either fully or partially some of the design recommendations for CCIS system features resulting from study 1 (discussed in section 6.3) as described in the functionality review of ACSZ in section 7.5. This has allowed us to test their validity in supporting CCIS activities in study 2 and to base the following design suggestions on the study 2 findings discussed earlier in this chapter. This section presents the design suggestions that support the CCIS process and also revisits the related design recommendations discussed in section 6.3.

Providing an Overview of the information presented

The findings in study 2 (findings 11 and 23) showed that users benefited from viewing overviews of shared workspace awareness information. In such an information-rich interface, both VI and sighted users benefit from overviews of information. Information seeking research has long demonstrated the importance of providing overviews for users when examining a large amount of information, as discussed in (section 6.3.1). The user can then have the option to zoom-in to the desired information whether its search results pages (as in REC1 in section 6.3.1) or workspace awareness information (as ACSZ partially provides through its recent activity region). REC 1 from study 1 has particularly highlighted the need for providing an overview of search results to enhance VI users experience, however in study 2 it was clear that both VI and sighted participants benefited from the overview of workspace awareness information. Therefore here we emphasize the importance of providing overview information about web search results to enhance VI user search result exploration and of providing an overview of awareness information to all users.

Design suggestion 1- Include overviews of individual search results and group and workplace awareness information to support the performance of both VI and sighted users.

The benefit of providing an overview of awareness information in a CIS context has been very rarely looked at in main stream CIS studies. Two studies (Paul and Morris, 2011; Kelly and Payne, 2014) have revealed that viewing team members search histories tends to be overwhelming and often participants report difficulties in going through them. Paul and Morris (2011) has recommend adding a filtering option to maximize user benefit when going through workspace awareness information. Making such a mechanism available to users can speed up their search process by allowing them to manage their time more efficiently. Furthermore the benefits of providing an overview of awareness information are likely to increase with the size of the team involved in the CIS process. In REC2 from study 1 we suggested allowing users to filter, cluster, and group search results. Here we advise broadening this perspective also to include all awareness information made available by the interface.

Design suggestion 2- Add mechanisms for categorizing, filtering and clustering awareness information made available to make the process of navigating easier.

According to study 2 (finding 23) VI users preferred the recent activity region more than their sighted peers and many have expressed its usefulness in providing an overview of updates in the shared workspace. This showed one fairly effective way of providing some of this information within a CCIS context, however a CCIS designer needs to consider the different access modalities involved. Providing an auditory overview of information is completely different than providing a visual overview of information. As discussed in 2.8.4 very few researchers have explored providing an auditory overview of webpages and given the increasingly complex structure of web documents, this remains an open problem (Stockman and Nickerson, 2013).

Providing an integrated interface

REC4 from section 6.3 highlighted the potential of having an integrated solution that allows collaborators to keep track of information encountered, be aware of updates in the shared workplace, and easily communicate and share web search results. The findings of study 2 revealed that an integrated system such as ACSZ had positive effects on both the participants' performance and levels of satisfaction. Having one integrated interface can lower the work load during a CIS task. Participants in study 2 communicated less information because it was automatically made available by the ACSZ system. They were able to utilize their time more efficiently and hence completed more of the task, as reported in finding 18.

Supporting group and workspace awareness

The majority of the information exchanged between participants was about the progress of the IS process (i.e. group awareness information) (finding 7 and 8) as ACSZ provides a wealth of information about the shared workspace, yet very little group awareness information. Implicit group awareness information such as collaborators' searches, including clicks, queries, and other actions can also provide increased awareness in distributed collaborations (Morris et al., 2008). This can help make collaborative search more efficient by reducing the need for explicitly asking group members for their activities such as their recent queries and so reduce redundancy of effort. In fact Shah and Marchionini (2010) have shown that when provided with group and workspace awareness information, users perform better than when provided with only workspace awareness. REC10 and REC11 from study 1 stated the importance of providing group awareness information related to the progress of the search task.

As we have seen in study 2 findings (findings 8 and 9) implicitly providing workspace awareness information through ACSZ features has lowered the amount of information exchange between collaborators. This helped them in reducing effort in reporting their contributions and progress through the use of communication channels. This agrees with early findings in the field of CSCW that confirmed that passive (implicit) awareness made available to team members allows them to effectively coordinate their work (Dourish and Bellotti, 1992). In the context of CCIS our findings suggested (REC9 from study 1) that a designer needs to provide mechanisms to facilitate workplace awareness information to improve users' coordination. Mainstream CIS interfaces have introduced workspace awareness information in different ways. While some simply present colour-coded user comments (Morris et al., 2010a), other work has provided multimodal representations of workplace awareness information by combining audio and visual alerts (Morris et al., 2004). These differences in presenting awareness information highly depend on the mode of interaction, the settings, and the type of information to be exchanged.

According to finding 8 participants tended to provide more group awareness information about their current actions. This highlights the importance of providing participants with their team members current activities such as query terms entered, web search results, and websites visited. This was a suggestion in study 1 REC10. Study 1 REC11 also recommended providing information about the previous action. In study 2 it was observed that providing group awareness information about current action occurred more frequently than providing awareness information about previous action. Finding 8 also revealed that most of the information users exchanged relating to workspace awareness information was about past actions. A study by Shah (2013a) showed that information exchanged relating to current actions had the highest proportion. However the study did not separate the group awareness information from workspace awareness information. Our finding suggest that the collaborators are more concerned with their current group related actions and past workspace related actions, thus a designer of a CCIS system should provide support for both of these types of awareness information.

Design suggestion 3- Provide group awareness information about current actions and workspace awareness about past actions. Group awareness information includes query terms entered, search results pages being viewed and websites being browsed. Workplace awareness information includes all updates that have been made in the shared workspace.

Improving the type and availability of awareness information

The findings from study 2 have revealed that the type and availability of awareness information can impact users experience, coordination effort and performance. Finding 11 showed that in each condition (co-located or distributed), participants used the received information for different purposes. While in the distributed setting the largest amount of information was to avoid duplication of effort, in the co-located setting the largest proportion of information exchanged was critical information without which the participants could not continue with the task. Studies in mainstream CIS emphasized that there are unique design considerations that must be taken into account when designing for co-located collaboration (Amershi and Morris, 2008; Morris et al., 2010a). The awareness information made available for a group of people working on the same task in the same place is different than when people work remotely. Morris et al. (2004) and (2006) assert that when people work in the same place, they have access to more awareness information from just seeing their team members interact and listening to their feedback. Moreover they tend to divide the labour differently. The latter was observed in both study 1 and study 2.

Design suggestion 4- the designer needs to take into consideration the variations between both settings when designing a CCIS interface, particularly in respect of providing the right awareness information for the right setting.

Designers can benefit from the role of awareness of other group members' activities by exploring the use of sound to provide ambient awareness. Studies have explored the role of ambient awareness in media spaces (systems that employ media such as video and audio to create a shared "space" for distributed work groups) (Smith and Hudson, 1995), and using spatialized non-speech audio to provide awareness of the activities of users working on different segments of a very large display (Muller-Tomfelde and Steiner, 2001).

Design Suggestion 5- Consider supporting ambient awareness through the use of audio to provide awareness of different aspects of the process.

The findings of study 2 revealed that both VI and sighted participants either visited the folders or viewed the recent activity region to view workplace awareness information (finding 23 and 11). They were also observed viewing past searches to update their awareness of the query terms used by their group (finding 11 and 13). Even though a user would know when a change has happened in the shared workplace via the interface awareness mechanisms (either by the audio alert for VI users or the popup message for sighted users); users also tend to look for this information again for a variety of reasons. This highlights the importance of having a persistent "upon request" awareness mechanism in a CCIS interface that allows collaborators to easily have an overview of shared workspace and group progress information when needed. Mainstream CIS systems have implemented "upon request" awareness mechanisms by having views or widgets in the interface that provide the user with views of their team members' activities. SearchTogether (Morris and Horvitz, 2007a) introduced a widget that they called the "Query awareness region"; it displays the query history for each user in order to maintain awareness of group members search strategies. Their aim was to provide a persistent, easy to reach widget that enables lightweight collaboration. Paul and Morris (2009) extended the SearchTogether interface by adding four views that allowed users to have access to data from a CIS session. This data included: the search query terms, the shared comments, the websites browsed and actions performed by each collaborator. The user is able to navigate to any view at any time to get an overview of group and workspace awareness. They suggest that this can be beneficial for sense-making and facilitating awareness. ACSZ provided a recent activity region that allowed users to have an overview of updates happening in the shared workplace which appear to be very popular especially with VI users (finding 23). A CCIS interface designer can achieve this by providing a place where such information is stored persistently.

Design suggestion 6- Provide users with a command that allows them to easily navigate to a widget or get an overview of awareness information of different activities in the CIS process and shared workspace.

Multimodal representation of awareness information

While as discussed above cross-modality is important, it was also observed that having a multi-modal representation of some awareness information can positively increase the engagement of collaborators. It was observed that sighted participants did not notice the arrival of a new chat message when they were engaged in performing other actions in the interface, as ACSZ only provides audio alerts for JAWS users. In fact the common pattern of behaviour observed was that the sighted users would usually check the chat messages received after completing a sub-task. VI participants on the other hand usually noticed the arrival of a new chat message because the JAWS script provides an audio alert. The result of the delayed response by sighted users meant that their VI partner would have to wait some time to receive a reply from their sighted partner. Therefore having a multimodal representation of awareness information can increase opportunities for users' engagement in collaborative activities (Metatla et al., 2012).

Audio has long been introduced to augment the process of collaboration (Gaver, 1992). In groupware, it has been used to provide feedback (Muller–Tomfelde and Steiner, 2001) as well as awareness information of other group members' activities (Smith and Hudson, 1995). Audio has been used in mainstream CIS, in particular in co-located conditions, where interactive boards, wall displays and table tops have been employed to provide auditory alerts alongside visual alerts to communicate information about users' actions (Morris et al., 2004).

Design suggestion 7- provide a multimodal representation of information to enhance users' experience. Care should be taken over the choices made concerning the type of information that is represented multimodaly, depending on the context. This is in the sense that audio information must not interfere with the user's actions, be distracting or cause the loss of other information through auditory masking.

10.5.2 Improving User's Experience when Accessing Mainstream CIS Interfaces Using an Access Tool

We implemented a number of enhancements to the ACSZ interface to improve VI users experience. In this section we reflect on this process and discuss the implications of utilizing available resources and access tool settings to improve the accessibility of a mainstream CIS interface which was not initially designed with accessibility in mind. We provide a set of design suggestions that can help in enhancing users experience when using a mainstream web-based interface.

Minimizing the effects of the access tool on the strategies considered in the division of labour

According to finding 5, similarly to study 1, participants divided the tasks in a way that the VI user performed the more accessible tasks. This decision was usually made by VI users based on their experience of using the web. In study 2 this affect was also apparent when participants were using the features of the interface. The average number of times sighted users created folders in the shared workplace was higher. Delegating this task to the sighted user allowed the VI user to put more effort into the search task. As discussed in the literature labour can be divided in various ways depending on a number of factors. The decisions made to divide labour can be setting-driven (Shah and Gonzalez-Ibanez,2011), resources-driven (Amershi and Morris, 2008), roles-driven (Pickens et al., 2008), or even accessibility-driven (Al-Thani et al., 2013). The designer need to minimize the effect of accessibility issues on the decisions made when dividing the labour.

Design suggestion 8- Ensure that all features are equally accessible by all the intended groups of users, in order to provide maximum flexibility of choice for team members about how they divide the labour.

The use of hot keys with speech-based screen readers

In the evaluated version of ACSZ using the JAWS script, the possibility of creating hot keys was limited, since we had no access to source code. Even though the use of hotkeys was limited, it was highlighted as being very well received (finding 20). Keyboard shortcuts (hot keys) are known to be one of the most effective ways that current screen readers enable VI users to navigate a webpage and can effectively improve the speed and ease of browsing webpages (Kouroupetroglou et al., 2007). In ACSZ adding more hot keys that can help users navigate to a component or perform an action can certainly enhance VI user's performance and user experience. If the original design of the original SearchTeam system had made full use of HTML headings, the capacity for improved usability using hotkeys would have been exploited further.

Design suggestion 9- Assign hotkeys to features which the designer anticipates that the user would frequently use to enhance user performance

Improving navigation experience using an access tool

During the accessibility review a number of navigation issues were highlighted in 7.6.5, to enhance the navigation experience of VI users we had two techniques in mind. Firstly by explaining the structure of the ACSZ website to users during training, and secondly by using PlaceMarkers for VI users.

In the first approach we allowed some time in the training session to demonstrate to VI users the major components of the interface. This included providing a verbal overview of the interface (as this is not currently fully possible with a screen reader), and enabling VI users to develop an understanding of the structure of the webpage by accessing each component, as described in 8.4.5. The knowledge the VI user develops of the webpage structure can contribute to a successful navigation strategy (Otter and Johnson, 2000). It can allow the screen reader user to develop a clear understanding of their current position by remembering their past actions and being aware of available paths leading from their current position.

In the second approach we introduced VI users to PlaceMarkers which allowed them to navigate easily to the major components in the interface. From findings (17, 19 and 21) it can be deduced that users benefited from both approaches. Being able to grasp the overall structure of the website before actually performing the web task allowed the user to engage in the task more efficiently rather than spending time in the beginning of the task to understand the structure of the webpage. Furthermore the use of PlaceMarkers provided VI users with a consistent view of the main four components that comprise the structure of the ACSZ webpage. By using PlaceMarkers, participants were able to have a quick option to navigate to the specific components and effectively enhance their performance and navigation experience.

The issue of webpage navigation using an access tool has long been highlighted by VI users themselves and by studies in the field of accessibility (Hillen and Evers, 2007). The WAI-ARIA framework (Craig et al., 2010) proposed adding semantic metadata about the webpage components. It is recommended in this framework to highlight the primary content, give the user information about the structure of the webpage, and facilitate drag and drop actions in the absence of a pointer tool or a mouse (Craig et al., 2010). To support VI users webpage navigation a webpage should be portioned into a number of landmarks allowing the user to have an enhanced overview of a webpage layout.

The field of cross-modal interaction has led to the formulation of guidelines for representing GUIs in a non-visual way. The work of (Mynatt and Weber, 1994) asserted that non-visual and visual interfaces must support the same mental model of the interface. It remains a problem in collaborative search that VI users perceive a webpage totally differently using a screen reader to how it is perceived by their sighted counterparts. A webpage which is rich in visual content is usually presented by a screen reader as a stream of single HTML tags. Not only are the objects themselves misrepresented but also their colours and shapes and their positions. For VI users most visual layout information is ignored or even misrepresented by a screen reader. This issue can be particularly problematic in a co-located setting where VI and sighted partners are jointly trying to view search results collaboratively. “Location disconnect” errors, as refer to by Stockman and Metatla (2008), occur when one participant does not know the focus of the other participant who is using a screen reader. This issue is handled by some screen readers better than others. For example, the Voiceover screen reader highlights the area being rendered by the screen reader to make it clear where the VI user is currently navigating on the page.

Design suggestion 10- When the web-based interface does not support the access mechanisms provided by an access tool, the designer needs to investigate how well an access tool user can navigate to the potential area within a web-based application. Understanding these navigational issues can help the designer in employing the appropriate access tool settings to enhance users' navigation experience through being able to navigate quickly to landmarks within a web-based interface.

The utilization of screen readers (access tools) utilities to enhance user's experience

In cases where the websites or the applications are not initially designed to support different modes of access the user is left with the option of adjusting the access tool to allow them to utilize it as effectively as possible. Different access tools provide different features in the form of scripting and other settings. Screen readers such as JAWS, Window-eyes, and NVDA allow users to adjust settings and build scripts which can be either global or specific to an application or web site. As discussed in section 7.10 the JAWS screen reader was chosen here because it remains the most widely used system and the one most commonly found in work settings. JAWS has scripting capabilities that have been widely used on different applications. After carrying out the accessibility review we were able to identify the barriers that users would encounter accessing the SearchTeam website using screen readers. In ACSZ we have used JAWS scripts to create a hot key to view chat messages, and create alarms and notifications. From the results and findings (finding 20) both features were very well-received and have a positive effect on VI user's experience and performance on the tasks. The use of place markers to enable rapid navigation to frequently used areas of the web site was also well-received by VI participants.

Design suggestion 11- To improve the user experience in interfaces that are not designed with accessibility in mind, the designer needs to evaluate the interface thoroughly using an analytical usability technique. The outcome of this process allows the designer to identify the conditions that make it difficult for the target users to achieve a goal when using the website in the specific context of use. After identifying the barriers, the designer needs to adjust the settings of the access tool where possible and develop scripts to improve accessibility.

10.6 Chapter Summary

Following Chapters 8 and 9 that presented an in-depth discussion about what happens to the cross-modal collaborative interaction when a tool is introduced specifically to support it, this chapter started by presenting the findings. The findings aimed to answer the research questions from the collaborative-focus perspective (section 10.2) and the user-focused perspective (section 10.3). The chapter contains an analysis of the effects of the ACSZ interface on the CCIS process in section 10.4. The Chapter concludes with a compilation of a set of design suggestions toward the inclusive design of CIS systems. In the following chapter, we present an overview of the thesis, we outline the main contributions to research and we conclude by discussing the different possibilities for future work.

Chapter 11 Conclusions and Future Work

11.1 Overview of the Thesis

To the best of our knowledge CCIS has not been explored before, and Chapter 2 presents a background study of the different factors that contributed in forming a knowledge base for this research. It started with the area of IS, given that this is the core process. It then presented an in-depth review of the field of CIS by presenting the models and frameworks in the literature. It reviewed the different aspects and dimensions of CIS and discussed the tools implemented to explore and validate these models and frameworks. It then discussed the different evaluation approaches applied in this field. The third area that Chapter 2 covers is the field of web accessibility and its accompanying challenges. This section finishes with a brief overview of web accessibility evaluation approaches. Given that the essence of the topic is cross-modal, this chapter ends with an overview of work done to date on cross-modal interfaces.

Through this review we identified that while VI users' interaction with the web is quite heavily researched, though undoubtedly, not least due to the continual development of web technologies, there remain many difficult open questions. There is very much less research in the area of accessible IS by VI users, though the work of Sahib and colleagues (2014) has laid a foundation for future research in this area. An area in which we could find no previous work at all was that of CCIS between VI and sighted users.

Motivated by the fact that group work is ubiquitous throughout education and professional contexts, as is use of the web, the next step for us was to examine the existence of CCIS in the real world, and the relevance and validity of researching issues relating to it. Chapter 4 presents the findings of an online questionnaire that investigated VI and sighted users' collaborative search practices including the prevalence and frequency of CCIS activities, the type of tasks that trigger it and the methods and tools employed. We found that people do engage in such activities, using a variety of tools, in business and pleasure-related tasks. The results of the questionnaire largely motivated the work in this thesis.

We went on to conduct an observational study to understand the process when VI and sighted users search the web together, using tools that they usually employ (a web browser, note taker and preferred communications system). The study involved 14 pairs of VI and sighted participants performing collaborative web search tasks in co-located and distributed settings. In the study we look at CCIS activity from two viewpoints. Firstly we looked at the process of information seeking. To date, as discussed in the literature review, very few studies (Shah and González-Ibáñez, 2010) have examined the process of CIS or attempted to draw a framework and models that describe its processes, thus in this thesis we take the Marchionini and White (2008) model of individual information seeking and map its processes to the individual and collaborative IS activities performed. The way this model introduces IS activity in four separate stages helped us to explore how users go about performing each stage of the IS process - both individually and collaboratively - in the cross-modal context. The second viewpoint from which we examine the CCIS process, is the effect of cross-modal interaction on the fundamental concepts of CIS, including division of labour and awareness (Morris, 2008).

In terms of the stages of IS, our observations revealed that there was clear evidence of similarities between the stages of the individual IS process and the stages of CIS reported by Hyldegard (2009) and Shah and Gonzalez-Ibanez (2010). However as shown in the analysis section, section 5.6, there was evidence that the results exploration and management stages were performed collaboratively. The frequency of collaboration in performing these two stages largely differed. Collaboration occurred mostly in the search results exploration stage in the co-located sessions, and in both settings in the results management stage. In terms of cross-modal interaction, it was very clear that underlying individual IS issues faced by VI users enforced the collaborators to divide the labour in such a way as to avoid web accessibility barriers. Additionally, VI users spent considerably more time switching between the multiple applications being used than their sighted peers, which also had a negative effect on their engagement and performance levels in the collaborative task. The results also highlighted the need to provide a shared workspace and explicit awareness mechanisms to represent users progress on IS activities.

We wanted to further explore the information management stage following the observational study. Specifically we looked at approaches and methods users employed to store information for later use when they work collaboratively. We wanted to know their preferences and whether or not cross-modality would impose challenges at this stage.

In Chapter 6 we conducted scenario-based interviews with 7 VI and 7 sighted participants from study 1. In these interviews, we firstly explained a scenario and asked them to describe their actions. This narrative approach, which has previously been used in the field of inclusive design for individual IS (Sahib et al., 2013), allowed us to understand user behaviour and the challenges to be addressed. It also allowed us to gain insight concerning tools and approaches used by VI and sighted users to manage stored web search results. As an outcome of this study and the foregoing observational study reported in Chapter 5, we proposed a set of design recommendations for CCIS system features. These recommendations address several core aspects of CCIS systems including; the search, the shared workspace and awareness mechanisms. These features address the cross-modal aspects of the process.

After producing the design recommendations for CCIS system features, we turned to the question of whether VI users could benefit from the use of mainstream systems specifically designed to support CIS, which supported some or all of these recommended features. The motivation behind this approach was firstly due to the fact that implementing a whole system from the ground up was not feasible given the time scale of a PhD project. Secondly we knew from the survey conducted in Chapter 2 that there were some candidate systems that may support some of the identified features. Thirdly, from the viewpoint of inclusive design, improving the accessibility of an existing CIS system was more appealing. Thus, in Chapter 7, we surveyed mainstream CIS systems and tools to select the most eligible CIS system that had sufficient levels of accessibility and satisfied some or all of the design recommendations. From this survey we found three possible candidates systems, and we performed a functionality review and an accessibility evaluation for each system. In the functionality review we looked at the features of each of the candidate interfaces and examined to what extent they implemented the design recommendations of section 6.3. For the accessibility evaluation, we adapted the barrier walkthrough approach by Brajnik (2006). The barrier walkthrough approach is a means of evaluating the usability of a system that is informed by web accessibility guidelines, thus it helped us in identifying both accessibility and usability issues in the examined interfaces. For us, usability issues are as important as accessibility issues, as an interface can be accessible yet still users may not be able to complete a task on it (Correani et al., 2004).

In Chapter 7, we describe how the approach was conducted with two VI evaluators. The results showed that three candidate interfaces had a number of accessibility issues, such as missing or misleading alternative text, lack of alternative keyboard commands and dynamic content not being rendered. Additionally there were usability issues, such as problems with navigation and lack of system feedback. Due to the fact that we did not have access to the source code of the examined interfaces, we chose the interface with the least accessibility issues that satisfied the majority of the design recommendations for CCIS system features. To improve VI user experience, we introduced two types of enhancements respectively to support awareness of dynamic changes and navigation. We supported awareness of dynamic content by developing a JAWS Script that speaks dynamic changes to users. VI users' navigation was supported by introducing JAWS settings, such as PlaceMarkers to facilitate navigation to different areas of webpages. We also introduced keyboard shortcuts to assist users in reading received chat messages.

We evaluated this interface with the same 14 VI and sighted participants that took part in study 1. They performed a search task with substantially the same complexity and in both co-located and distributed settings as in study 1. Given the complexity of the interaction in such a study and the need to evaluate the interface being used, Shah (2014) proposed an evaluation framework for CIS interfaces which addressed three different dimensions of the process: the collaboration, user-interaction and the system. As we were not concerned with evaluating the internal algorithms of the CIS application, we discarded the third (system) dimension. In

Chapter 8, we describe the evaluation of the CCIS interface with respect to the collaborative dimension. This includes aspects such as the division of labour and awareness. In Chapter 9 we describe the evaluation from the user interaction perspective, which includes the individual IS process, user interaction in general and, specifically VI user interaction.

When looking into the collaborative dimension we took our first study (reported in Chapter 5) as a baseline. The comparative analysis of results reported in Chapter 10 showed that pairs performed slightly better in study 2 than study 1; they were significantly more satisfied with their performance and communication levels. We found that participants exchanged less information to facilitate awareness. It was also evident that the information exchanged was influenced by the information made available by the interface. The way participants divided labour was fairly similar to study 1, as VI users continued to aim to avoid tasks that involved visiting websites with accessibility issues.

Chapter 10 reported that interface design had an impact on IS behaviour and on VI and sighted users' interactions with the interface. Having the ability to view team members search results allowed participants to collaboratively make sense of retrieved information. Moreover, the design of the interface led to a more structured approach to organizing information retrieved. In comparison to study 1, the integrated system used in study 2 had the effect of reducing the time and effort spent in switching between applications, and so is likely to reduce cognitive load during CCIS tasks. VI users in particular benefited from the overview of activities provided by the interface, a fact that was highlighted in the post-study interviews. Hot keys provided VI users with a quick and efficient means to reach specific interface components, as evidenced through direct observations and user feedback in the post-study interviews. Chapter 10 concludes by detailing a set of design suggestions towards the inclusive design of CIS systems, grounded in the findings from the two studies and post-study interviews.

11.2 Contributions

The work in this thesis contributes to a number of different research areas, including CIS, inclusive design, accessibility, cross-modal interaction and information science. In this section we describe the contributions to knowledge that this thesis makes.

1. Identifying the problem and defining it

With the recent increase of research in the field of CIS, a number of surveys have tried to define the domain of CIS and provide a bases for research in this area (Morris, 2008; Capra et al., 2011). In fact, the survey by Morris (2008) is acknowledged to be the publication which gave rise to this thread of research. The preliminary survey described in Chapter 4 provided an initial basis for research in the sub-domain of CCIS. The evidence from the survey that CIS takes place within a cross-modal context provided the basis and motivation for the work of the thesis.

The survey suggested that CCIS is quite common and provided us with some initial information about the tools used, tasks performed and challenges experienced while performing CCIS. This survey adds to knowledge in the areas of CIS and inclusive design as it provides evidence that this problem actually exists and is quite common. It forms an initial basis for CCIS research.

2. A detailed exploratory investigation of the CCIS process between VI and sighted users

The study comprises two parts: the observational study in Chapter 5 and a series of follow-up, scenario-based interviews in Chapter 6. The observational study examined the main aspects of the process ranging from the stages of individual IS to the concepts and features of CIS. Very few studies in CIS have looked into analysing the content of conversations between collaborators; such as (Olson et al, 1992; Foster, 2009). The thesis contributes an original approach to analysing the conversation and categorising the information exchange between the participants, and looking into the usage of this information through video recordings and transcripts of the conversations. This allowed us to investigate CCIS behaviour and the challenges that arose due to the cross-modal interaction, the tools used and how the process was affected by the accessibility of the web sites visited to perform the tasks. We examined how users provided and used awareness information to support the task and different approaches used to divide the labour. As explained in the previous contribution, no prior work has investigated this area, hence the research provides the basis for a number of issues central to CCIS to be examined. The results of both the observational study and the follow-up interviews provides valuable insights into how VI and sighted users interact during IS activities, as well as into how both individual and group information seeking happens.

3. A research agenda to inform the design of features in a CCIS system

Research in the area of CIS has long designed and examined CIS interfaces for a variety of tasks. Usually the results of surveys (Morris, 2008) observations (Reddy and Jansen, 2008) and interviews (Shah and Marchionini, 2010) guide the design of these interfaces. These studies often propose a set of major components that a CIS interface should provide that usually includes a search engine, traditional communication tools, awareness mechanisms and persistent storage.

In this thesis section 6.3 provides details concerning the features that should be supported within CCIS systems and sets an agenda for research in this area. The features suggested in section 6.3 can be implemented in numerous different ways, and so we make these recommendations in the spirit of a research agenda or framework within which investigations can be undertaken to develop and evaluate alternative designs of the CCIS features proposed. The findings from the observational study and the follow-up scenario-based interviews form the evidence base from which these design recommendations have been synthesised. This contribution is offered in the hope that it may help to inform and/or provide a basis for future research in the design of systems that support CCIS.

4. An accessibility review of available mainstream general purpose CIS interfaces

As Chapter 7 describes there are numerous available solutions that support CIS in research or in the commercial world. However they come in many forms and serve different purposes. Chapter

7 provides a review that narrows down these numerous options to a few general purpose PC-based CIS interfaces. Benefiting from the research area of accessibility evaluation, we examined these interfaces further for their level of accessibility. This contribution highlights crucial accessibility and usability issues that can hinder screen reader's users from fully benefiting from a main stream CIS system. We introduce an analytical approach that a CIS designer can employ to examine the accessibility of an interface; this contributes to the field of accessible CIS.

5. A detailed investigation of the CCIS process involving VI and sighted users when using a mainstream CIS enhanced for accessibility.

Several previous researchers (Morris and Horvitz, 2007a; Kelly and Payne, 2014) have performed user evaluations with pairs of participants using a CIS interface. To the best of our knowledge, no such studies have examined collaborative, cross-modal behaviour with routinely used applications and employing a dedicated interface. In the study presented in Chapter 8, we used the results from study 1 (presented in chapter 5) as a baseline study which provided with insights into the differences in collaborative behaviour patterns, and processes manifested under these different conditions. It highlighted the effects the interface had on individual IS behaviour, awareness and user interaction. This contribution provides knowledge about how users employ interface features in performing CIS tasks. The integrated tool positively affected user experience and performance. The awareness features available enabled users to put less effort into coordination and so lead to improved task performance. This contributes knowledge concerning the design of CCIS systems as it shows the positive effects of interface features on users' engagement and performance. It also provides evidence that VI users benefited from the accessibility enhancements implemented, such as PlaceMarkers, hot keys and audio notifications. This contributes to the field of web accessibility and demonstrates that a few yet well studied adjustments made through scripting and changes to the settings of the access tool, can enable users experience, engagement and performance to be positively and effectively enhanced.

6. Design suggestions toward the inclusive design of CIS systems

As discussed in the literature review in section 2.9.2 there is very limited work in the field of cross-modal web interaction. The work of Murphy (2007b) is considered one of the very few publications to have provided suggestions to support designers when building webpages for cross-modal interaction. Therefore, we believe this evidence-based set of design suggestions compiled through the analysis and discussion of the results obtained in study 2, can effectively contribute to the fields of CIS, cross-modal web interaction and inclusive design.

11.3 Future Work

In this section on future work we discuss possible ways of progressing research on specific issues relating to CCIS arising from the thesis, as well as exploring specific areas of CCIS in different contexts and using different media.

11.3.1 Extending the Studies

The collaborative search task

In chapter 5 we have pointed out, in the limitations section, that the nature of the task impacts CIS activity. This is confirmed by a recent study by Tao and Tombros (2013) in which they found that when tasks can be decomposed easily into sub-tasks (such as travel planning), the process of sense-making differs. They assert that in such tasks, structured sense making often does not happen, as the structure is clear from the start. The same group performed a similar study (2014) with a different task, which is hard to decompose and had no common structure. This task required participants to research a topic they are not familiar with and prepare an outline for a presentation. In this study, they found participants put more effort into creating a structure by discussing and searching the web for information.

However in our study we had one type of task that involved planning a business or holiday trip. This type of task (Tao and Tombros, 2014) has a fairly clear structure. Future work could focus on employing tasks that do not have a natural structure for its results and which require collaborators to perform CIS in order for them specifically to discuss and create the structure of the task. This future work could examine how our findings map to different styles of tasks. We believe that this could impact the amount of discussion about the tasks, the information exchanged between participants and CIS behaviour. Future work could investigate the differences and report the CIS behaviour patterns that emerge.

The role of collaborators

In our studies it was quite commonly observed that VI users would divide the task in such a way to avoid websites they knew from previous experience may involve accessibility issues. This brings into focus a topic that is not heavily explored in the area of CIS, which is dividing labour differently according to users' roles. Previous CIS research has examined several models for the division of labour, as discussed in section 2.5.2. These models either depended on the search task (Taylor, 1968), the availability of resources (Morris et al., 2008) or the role and expertise of the collaborators (Pickens et al., 2008).

Future work could focus on extending the studies conducted by defining roles for participants. A way forward can be by applying Pickens et al. (2008) "Gatherer and Surveyor" model, in which one participant performs searches and the other participant reviews the search results. This would allow the measurement of the performance in terms of sub-tasks completed, the changes in information exchanged as well as providing insights into the challenges and issues encountered.

Investigating the design recommendations for features

In this thesis we started by investigating CCIS activity through conducting an observational study that revealed CCIS behaviour patterns of users and challenges faced. As a result in Chapter 6, we set an agenda for research in CCIS by establishing a number of design recommendations for CCIS systems. The chosen interface (ACSZ) satisfies a number of these design recommendations, and so study 2 allowed us to validate these design recommendations. Future work could focus on exploring the remaining design recommendations. These design recommendations have identified several areas in which there appears to be considerable scope to extend work on both the individual and collaborative aspects of the IS process. For example, From the individual users perspective, evaluating the effect of having a mechanism that allows VI users to have an overview of search results (REC1) on their performance and engagement in the collaborative process. This will help in understanding how best to support the process, and it would open up new avenues of research in terms of studying auditory overviews of information on the web. From the cross-modal interaction perspective, examining the use of sound in representing different changes made to the workspace (REC 9) and benefiting from knowledge that examined conveying information about group members' activities using sound, is another potential area for development (McGookin and Brewster, 2007; Metatla et al., 2012). Exploring cross-modal interaction in the context of information seeking can be considered a potential way forward for this study.

11.3.2 Beyond the Studies

Cross-modal mobile collaborative information seeking

In the scenario-based interviews conducted in Chapter 7 all seven VI and seven sighted interviewees used smart phones for web searches. In fact recent studies have revealed that collaborative searches are quite common using mobile technology in social settings (Church et al., 2012; Morris, 2013). Morris (2013) revealed that 65% of mobile searches are triggered by collaborative activities. These activities often happen in co-located settings (Teevan et al., 2014). These studies have only explored sighted user usage. However as reported by WebAIM (2014) VI user smart phone usage has increased in the last five years from 12% to 82% of the surveyed population.

Given this popularity and the rapid increase in smart phone usage, exploring cross-modal collaborative mobile searching should certainly be considered a fruitful avenue of future research. A number of mainstream applications do provide some support for cross-modal mobile collaborative information seeking (CMCIS) such as the Coagmento and Diigo mobile applications. After determining that the mobile application to be used provides or can be tailored to provide sufficient accessibility, this could lead to an investigation of CMCIS activity and its challenges. This should also include identifying behaviour patterns that occur in searching, sharing retrieved search results and user communications. This could be considered as a first step towards providing solutions to support CMCIS.

Employing social networking websites in CCIS

In the scenario-based interviews, both VI and sighted users mentioned that they used the Twitter social networking tool as a means to communicate and share information when performing CIS activities. Moreover, a recent study by Brady et al. (2013) found that usage of social networking websites is quite popular among VI web users. In a sample of 191 VI respondents to an online survey, 80% were Facebook users and 50% were Twitter users. Employing social networking websites to support CIS activity has been investigated in previous research (Morris, 2013; Capra et al., 2011). These studies revealed that users do employ social network websites in CIS activity. Morris (2013) who surveyed 167 web users in the United States, stated that 50% of the surveyed Facebook users and 33.3% of surveyed Twitter users used that platform for CIS activity as a tool to share and discuss retrieved information.

Employing social networking websites in such activities has been investigated in mainstream CIS research (Hecht et al., 2012; Morris and Teevan, 2010). Additionally tools such as Diigo and the Bing toolbar (Shum and Connell, 2012) allow users to share and discuss web search results with social network users. Considering the fact that people are becoming increasingly familiar with the use of social network websites, future work could explore this thread of research from a cross-modal perspective. Investigating ways in which users can employ these social networking outlets to support CIS tasks, exploring the costs and benefits of such communications and the user behaviour that arises, could be important in developing support for CCIS activity and hence the inclusion of VI users in educational and work settings.

Bibliography

Akoumianakis, D., and Stephanidis, C. (2003). Blending scenarios of use and informal argumentation to facilitate universal access: experience with the Universal Access Assessment Workshop method. *Behaviour and Information Technology, 22*(4): 227–244.

Al-Thani, D., Stockman, T. (2010). Development and evaluation of a cross-modal XML schema browser. In *Proceedings of the 16th International Conference on Auditory Display Washington D.C., USA*.

Al-Thani, D., Stockman, T., and Tombros, A. (2013). Cross-modal collaborative information seeking (CCIS): an exploratory study. In *Proceedings of the 27th International BCS Human Computer Interaction Conference*, pages16-24, British Computer Society.

Almeida, L. D. A., & Baranauskas, M. C. C. (2012). Accessibility in rich internet applications: people and research. In *Proceedings of the 11th Brazilian Symposium on Human Factors in Computing Systems*. Pages. 3–12. Brazilian Computer Society.

Allen, T. J. (1977). *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R and D Organization* (MIT Press Books). The MIT Press.

Amershi, S., and Morris, M. R. (2008). CoSearch: a system for co-located collaborative web search. *Proceedings of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, CHI ’08, pages 1647–1656, New York, NY, USA.

Andriessen JH (1996) "The Why, How and What to Evaluate of Interaction Technology: A Review and Proposed Integration". In P. Thomas, editor, *CSCW Requirements and Evaluation*, pages 107-124. Springer-Verlag.

Andronico, P., Buzzi, M., Castillo, C., and Leporini, B. (2006). Improving search engine interfaces for blind users: a case study. *Universal Access in the Information Society, 5*(1): 23–40.

Aula, A., Jhaveri, N., and Käki, M. (2005). Information search and re-access strategies of experienced web users. In *Proceedings of the 14th international conference on World Wide Web* (WWW), pages 583–592, New York, NY, USA. ACM.

Baeza-Yates, R. and Pino, J. A. (1997). A first step to formally evaluate collaborative work. In *Proceedings of the international ACM SIGGROUP conference on Supporting group work: the integration challenge* (GROUP '97). Pages 56-60, New York, NY, USA. ACM.

Bangor, A. W., and Miller J. T., (2008) Multimode Interfaces: Two or More Interfaces to Accomplish the Same Task. In Kortum, P. editor. HCI beyond the GUI: design for haptic, speech, olfactory and other nontraditional interfaces. Morgan Kaufmann.

Bates, M. J. (1989). The design of browsing and berry picking techniques for the online search interface. Online review, 13(5): 407–424.

Belkin, N. J., and Croft, W. B. (1992). Information filtering and information retrieval: two sides of the same coin?. *Communications of ACM. ACM*, *35*(12), 29–38.

Bergman, E., and Johnson, E. (2001). Towards accessible human-computer interaction. *Microsystems Laboratories*.

Blandford, A. (2013). Semi-structured qualitative studies. In Soegaard, M. and Dam, R. F., Editors. *The Encyclopedia of Human-Computer Interaction*, the Interaction Design Foundation.

Blattner, M. M., Smikawa, D. A., and Greenberg, R. M.(1989). Earcons and Icons: their structure and common design principles. *Human–Computer Interaction*.1989 (4): 11–44.

Boardman, R., and Sasse, M. A. (2004). ‘Stuff goes into the computer and doesn’t come out’: a cross-tool study of personal information management. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, CHI ’04, pages 583–590. New York, NY, USA. ACM.

Bodker, S. (2000). Scenarios in user-centred design—setting the stage for reflection and action. *Interacting with Computers*, *13*(1): 61–75.

Borgatti, S. P., and Cross, R. (2003). A relational view of information seeking and learning in social networks. *Management science*, 432–445.

Borodin, Y., Mahmud, J., Ramakrishnan, I., and Stent, A. (2007). The HearSay non-visual web browser. In *Proceedings of the 2007 international cross-disciplinary conference on Web accessibility (W4A)*, pages128–129. New York, NY

Brady, E. L., Zhong, Y., Morris, M. R., and Bigham, J. P. (2013). Investigating the appropriateness of social network question asking as a resource for blind users. In *Proceedings of the 2013 conference on Computer supported cooperative work*, pages 1225–1236. New York. ACM.

Brajnik, G. (2006). Web accessibility testing: when the method is the culprit. *Computers Helping People with Special Needs*, 156–163.

Brajnik, G., Yesilada, Y., and Harper, S. (2010). Testability and validity of WCAG 2.0: the expertise effect. In *Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility*, pages. 43–50. New York, NY, USA. ACM.

Brewster, S.A. (1996). A sonically enhanced interface toolkit. In *Proceedings of International Conference on Auditory Display (ICAD'96)*, pages 47-50, Palo Alto, USA.

Brown, A., Jay, C., Chen, A. Q., and Harper, S. (2012). The uptake of Web 2.0 technologies, and its impact on visually disabled users. *Universal Access in the Information Society*, *11*(2):185–199.

Bruce, H., Jones, W., and Dumais, S. (2004). Keeping and re-finding information on the web: What do people do and what do they need?. In *Proceedings of the American Society for Information Science and Technology*, *41*(1):129–137.

Bruce, H., Fidel, R. Pejtersen, A.M., Dumais, S., Grudin, J. and Poltrock, S. (2003). A comparison of the collaborative information retrieval (CIR) behaviors of two design teams. *New Review of Information Behaviour Research*, 4:139-153.

Bryan-Kinns, N., Stockman, T., and Metatla, O. (2010). Collaborative Cross-Modal Interfaces. In *Proceeding of Digital Futures'10 Research Councils UK Digital Economy All Hands Meeting*, Nottingham, UK.

Bystrom, K., and Jarvelin, K. (1995). Task complexity affects information seeking and use. *Information Processing and Management*, *31*(2):191–213.

Caldwell, B., Cooper, M., Reid, L., and Vanderheiden, G. (n.d.). Web Content Accessibility Guidelines 2.0 (WCAG 2.0). W3C, 2008.

Capra, R. (2003). Mobile Information Re-Finding as a Continuing Dialogue. In *Proceeding of CHI '03 Extended Abstracts on Human Factors in Computer Systems,* pages 664-665, New York, NY. ACM.

Capra, R., Chen, A. T., Hawthorne, K., Arguello, J., Shaw, L., and Marchionini, G. (2012). Design and evaluation of a system to support collaborative search. In *Proceedings of the American Society for Information Science and Technology*, *49*(1): 1–10.

Capra, R., Marchionini, G., Velasco-Martin, J., and Muller, K. (2010). Tools-at-hand and learning in multi-session, collaborative search. In *Proceedings of the 28th international conference on Human factors in computing systems* (CHI ’10), pages 951–960. New York, NY, USA: ACM.

Capra, R. G., and Perez-Quinones, M. A. (2003). Re-Finding Found Things: An Exploratory Study of How Users Re-Find Information. Technical Report, Virginia Tech.

Capra, R., Velasco-Martin, J., and Sams, B. (2011). Collaborative information seeking by the numbers. In *Proceedings of the 3rd international workshop on Collaborative information retrieval*, pages 7–10. Glasgow, United Kingdom.

Carey, K., and Stringer, R. (2000). *The Power of Nine: A Preliminary Investigation Into Navigation Strategies for the New Library with Special Reference to Disabled People*. Library and Information Commission.

Carroll, J. M. (2000). *Making use: scenario-based design of human-computer interactions*. MIT press.

Chandrashekar, S., Stockman, T., Fels, D., and Benedyk, R. (2006). Using think aloud protocol with blind users: a case for inclusive usability evaluation methods. In *Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility* (Assets ’06), pages 251–252. New York, NY, USA. ACM.

Chen, A. Q. (2013). *Automatic Web widgets prediction for Web 2.0 access technologies*. *PhD Thesis*, University of Manchester, Manchester, United Kingdom.

Chen, A. Q., Harper, S., Lunn, D., and Brown, A. (2013). Widget identification: a high-level approach to accessibility. *World Wide Web*, *16*(1): 73–89.

Chen, A. T., Capra, R., and Wu, W.-C. (2014). An investigation of the effects of awareness and task orientation on collaborative search. In *Proceedings of the American Society for Information Science and Technology, 51*(1): 1–10.

Chisholm, W. A., and Henry, S. L. (2005). Interdependent components of web accessibility. *Proceedings of the 2005 International Cross-Disciplinary Workshop on Web Accessibility (W4A),* pages 31–37. New York, NY, USA. ACM.

Church, K., Cousin, A., and Oliver, N. (2012). I wanted to settle a bet!: understanding why and how people use mobile search in social settings. In *Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services,* pages 393–402. New York, USA. ACM.

Clarkson, P. J., and Keates, S. (2003). Inclusive Design: A Balance Between Product Demands and User Capabilities. In *Proceeding ASME 2003 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, pages 575–584. American Society of Mechanical Engineers.

Cooper, M. (2007). Accessibility of emerging rich web technologies: web 2.0 and the semantic web. In *Proceedings of the 2007 international cross-disciplinary conference on Web (W4A),* pages 93-98, New York, USA. ACM.

Corbin, J. M., and Strauss, A. C. (2008). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (Third ed.). Sage Publications, Inc.

Cormode, G. and Krishnamurthy, B. (2008) Key differences between Web 1.0 and Web 2.0, *First Mondy*. (13)6.

Correani, F., Leporini, B., and Paternò, F. (2004). Supporting Web Usability for Vision Impaired Users. In *User-centered interaction paradigms for universal access in the information society*, pages 242–253. Springer.

Craig, J., Cooper, M., Pappas, L., Schwerdtfeger, R., and Seeman, L. (2010). Accessible Rich Internet Applications (WAI-ARIA) 1.0. World Wide Web Consortium, Working Draft WD-wai-aria-20100916.

Craven, J. and Brophy, P. (2003). Non-visual access to the digital library: the use of digital library interfaces by blind and visually impaired people. Technical report 145, CERLIM, Manchester: Centre for Research in Library and Information Management.

D'agostino, R. B., Belanger, A., and D'Agostino Jr, R. B. (1990). A suggestion for using powerful and informative tests of normality. *The American Statistician*, *44*(4): 316–321.

Denning, P. J., and Yaholkovsky, P. (2008). Getting to "We." *Communication of ACM*, *51*(4): 19–24.

Dervin, B. (1983). An overview of sense-making research: concepts, methods and results to date. In *Processing of International Communications Association Annual Meeting*. Dallas, Texas, USA.

Dingwall, O., Lê, M.-L., Monnin, C., Szwajcer, A., and Vokey, S. (2014). Where Do You Want to Meet? Assessment and Evaluation of Virtual Meeting Software. *Journal of the Canadian Health Libraries Association/Journal de l'Association Des Bibliothèques de La Santé Du Canada*, *35*(2), 64–67.

Dourish, P., and Bellotti, V. (1992). Awareness and coordination in shared workspaces. In *Proceedings of the 1992 ACM conference on Computer-supported cooperative work* (CSCW '92), pages 107–114. New York, NY, USA.

Dumais, S., Cutrell, E., Sarin, R., and Horvitz, E. (2004). Implicit queries (IQ) for contextualized search. In *Proceedings of the 27th annual international ACM SIGIR conference on Research and development in information retrieval* (SIGIR '04), pages 594–594. New York, NY, USA.ACM.

Dumas, J.S., Redish, J.C., 1994. A Practical Guide to Usability Testing. Ablex, Norwood, NJ.

Efthimiadis, E.N. (1996). Query expansion. *Annual Review of Information Systems and Technology*, 31: 121-187.

Ellis, D. (1989). A Behavioural Approach to Information Retrieval System Design. *Journal of Documentation*, *45*(3): 171-212.

Ellis, C. A., Gibbs, S. J., and Rein, G. (1991). Groupware: some issues and experiences. *Communications of the. ACM*, *34*(1): 39–58.

Ellis, K., and Kent, M. (2010). *Disability and new media*. Routledge.

Evans, B. M., and Chi, E. H. (2008). Towards a model of understanding social search. In *Proceedings of the 2008 ACM conference on Computer supported cooperative work*, pages 485–494, New York, USA. ACM.

Evans, B. M., Kairam, S., and Pirolli, P. (2010). Do your friends make you smarter?: An analysis of social strategies in online information seeking. In *Information Processing and Management*, *46*(6): 679–692.

Farnham, S. D., Lahav, M., Raskino, D., Cheng, L., and Laird-McConnell, T. (2012). So. cl: An Interest Network for Informal Learning. In *Proceeding of Sixth International AAAI Conference on Weblogs and Social Media* (ICWSM). Dublin, Ireland.

Farooq, U., Ganoe, C. H., Carroll, J. M., and Giles, C. L. (2009). Designing for e-science: Requirements gathering for collaboration in CiteSeer. *International Journal of Human-Computer Studies*, *67*(4): 297–312.

Faulkner, S. (2010). HTML5 and the myth of WAI-ARIA redundance. The Paciello Group Blog. Retrieved from: https://www.paciellogroup.com/blog/2010/04/html5-and-the-myth-of-wai-aria-redundance/

Fernández-Luna, J. M., Huete, J. F., Pérez-Vázquez, R., and Rodrıguez-Cano, J. C. (2010). COSME: A NetBeans IDE plugin as a team-centric alternative for search driven software development. In *Proceeding of Group 2010: First Workshop on Collaborative Information Seeking*, Florida, USA.

Fidel, R., Bruce, H., Pejtersen, A., Dumais, S., Grudin, J., and Poltrock, S. (2000). Collaborative information retrieval. *The New Review of Information Behaviour Research*, *1*(1): 235–247.

Flick, U. (2009). *An Introduction to Qualitative Research* (Fourth Edition edition). SAGE Publications Ltd.

Fogli, D., Provenza, L. P., and Bernareggi, C. (2010). A design pattern language for accessible web sites. In *Proceedings of the International Conference on Advanced Visual Interfaces*. Pages 307–310. New York, NY, USA. ACM.

Foley, C., and Smeaton, A. F. (2010). Division of labour and sharing of knowledge for synchronous collaborative information retrieval. *Information Processing and Management*, *46*(6): 762–772.

Foster, J. (2006). Collaborative information seeking and retrieval. *Annual Review of Information Science and Technology (ARIST),* 40:329-356.

Foster, J. (2009). Understanding interaction in information seeking and use as a discourse: a dialogic approach. *Journal of Documentation*, *65*(1): 83–105.

Foster, J. (2010) Collaboration as co-constructed Discourse: Developing a Coding Guide for the Analysis of Peer Talk during Educational Information Seeking. In Foster, J. Editor, *Collaborative Information Behavior: User Engagement and Communication Sharing: User Engagement and Communication Sharing*. IGI Global.

Fraternali, P., Rossi, G., & Sánchez-Figueroa, F. (2010). Rich Internet Applications. *IEEE Internet Computing*, 14(3), 9–12. http://doi.org/10.1109/MIC.2010.76

Fu, X., Kelly, D., and Shah, C. (2007). Using collaborative queries to improve retrieval for difficult topics. In *Proceedings of the 30th annual international ACM SIGIR conference on Research and development in information retrieval* (SIGIR ’07), pages 879–880. New York, NY, USA: ACM.

Gaver, W. W. (1986). Auditory icons: Using sound in computer interfaces. *Human-Computer Interaction*, 2(2), 167–177.

Gaver, W. W. (1992). The affordances of media spaces for collaboration. *Proceedings of the 1992 ACM conference on Computer-supported cooperative work* (CSCW ’92), pages 17–24. New York, NY, USA. ACM.

Gibson, B. (2007). Enabling an accessible web 2.0. *Proceedings of the 2007 international cross-disciplinary conference on Web accessibility (W4A)*, pages 1–6. New York, NY, USA. ACM.

Golovchinsky, G., and Diriye, A. (2011). Session-based search with Querium. In *Proceeding of Human Computer and Information Retrieval (HCIR) conference*. ACM.

Golovchinsky, G., Pickens, J., and Back, M. (2009). A taxonomy of collaboration in online information seeking. In *JCDL Workshop on Collaborative Information Retrieval*, 2008.

González-Ibáñez, R., Haseki, M., and Shah, C. (2013). Let's search together, but not too close! An analysis of communication and performance in collaborative information seeking. *Information Processing and Management*, *49*(5):1165–1179.

González-Ibáñez, R., and Shah, C. (2014). Performance Effects of Positive and Negative Affective States in a Collaborative Information Seeking Task. In *Collaboration and Technology,* pages 153–168. Springer.

Goose, S., and Moller, C. (1999). A 3D audio only interactive Web browser: using spatialization to convey hypermedia document structure. In *Proceedings of the seventh ACM international conference on Multimedia (Part 1), pages* 363–37, New York, USA. ACM.

Gutwin, C., and Greenberg, S. (2002). A Descriptive Framework of Workspace Awareness for Real-Time Groupware. In *Computer Supported Cooperative Work (CSCW)*, *11*(3): 411–446.

Hailpern, J., Guarino-Reid, L., Boardman, R., and Annam, S. (2009). Web 2.0: blind to an accessible new world. In *Proceedings of the 18th international conference on World wide web*, pages 821–830. New York, USA. ACM.

Halvey, M., Vallet, D., Hannah, D., Feng, Y., and Jose, J. M. (2010). An asynchronous collaborative search system for online video search. In *Information Processing and Management*, *46*(6): 733-748.

Hansen, P., and Järvelin, K. (2005). Collaborative Information Retrieval in an information-intensive domain. *Information Processing and Management*, *41*(5): 1101–1119.

Harper, S., and Patel, N. (2005). Gist summaries for visually impaired surfers. In *Proceedings of the 7th international ACM SIGACCESS Conference on Computers and Accessibility,* pages. 90–97. New York, USA. ACM.

Hart, S. G., and Staveland, L. E. (1988). Development of NASA – TLX (Task Load Index): Results of Empirical and Theoretical Research. In P. A. Hancock and N. Meshkati (Eds.), Human Mental Workload(pp. 239-250). North Holland Press.

Hertzum, M. (2008). Collaborative information seeking: The combined activity of information seeking and collaborative grounding. In *Information Processing and Management*, *44*(2), 957–962. doi:10.1016/j.ipm.2007.03.007

Hewett, R., (2015). Investigation of data relating to blind and partially sighted people in the quarterly Labour Force Survey: October 2011 – September 2014. RNIB. Retrieved from: http://www.rnib.org.uk/knowledge-and-research-hub-research-reports/employment-research/labour-force-survey-2015

Hearst, M. A. (2009). Search User Interfaces. Cambridge University Press, New York.

Hecht, B., Teevan, J., Morris, M. R., and Liebling, D. J. (2012). SearchBuddies: Bringing Search Engines into the Conversation. In *Proceeding of the 6th International AAAI conference on Weblogs and Social Media (ICWSM)*, pages 138–145. Dublin, Ireland.

Henry, S. L., & May, M. (2009). User agent accessibility guidelines (uaag) overview. Retrieved from: http://www.w3.org/WAI/intro/uaag.html

Hillen, H., and Evers, V. (2007). Website navigation for blind users. In In Y. Sharp, H. Rogers and J. Preece, Editors, *Interaction Design: Beyond Human-Computer Interaction. 2nd Ed. John Wiley and Sons, Ltd.*, Chichester, United Kingdom.

Hoppe, H., and Zhao, J. (1994). C-TORI: An interface for cooperative database retrieval. In *Proceeding of the 5th International Conference on Database and Expert Systems Application*, 103-113, London, UK.

Horton, S., and Leventhal, L. (2008). Universal Usability. In Harper, S. and Yesilada, Y., Editors, *Web Accessibility*, pages 346-355. London: Springer London.

Hudson, W. (2004). Inclusive design: accessibility guidelines only part of the picture. *Interactions*, *11*(4): 55–56.

Hyldegard ,J. (2009). Beyond the search process–Exploring group members' information behavior in context. *Information Processing and Management*, 45(1):142–158.

Hypponen, H. (2000). *Handbook on inclusive design of telematics applications*. Stakes.

Ivory, M. Y., and Chevalier, A. (2002). A study of automated web site evaluation tools. Technical Report, University of Washington, Department of Computer Science.

Ivory, M. Y., Yu, S., and Gronemyer, K. (2004). Search result exploration: a preliminary study of blind and sighted users' decision making and performance. In *Proceedings of CHI'04* *extended abstracts on Human factors in computing systems,* pages 1453–1456. New York, USA. ACM.

James, F.(1997). Presenting HTML Structure in Audio: User Satisfaction with Audio Hypertext, *In Proceedings of the International Conference on Auditory Display (ICAD97),* pages 97-103 California, USA.

Jay, C., Lunn, D., and Michailidou, E. (2008). End user evaluations. In Harper, S. and Yesilada, Y., Editors, *Web Accessibility,* pages 107–126. London: Springer London.

Jones, W. (2007). Personal information management. *Annual review of information science and technology*, *41*(1): 453–504.

Jones, W., Bruce, H., and Dumais, S. (2001). Keeping found things found on the web. In *Proceedings of the tenth international conference on Information and knowledge management* (CIKM '01), pages 119–126. New York, NY, USA: ACM.

Jones, W., Phuwanartnurak, A. J., Gill, R., and Bruce, H. (2005). Don't take my folders away!: organizing personal information to get ghings done. In *CHI '05 extended abstracts on Human factors in computing systems* (CHI EA '05), pages 1505–1508. New York, NY, USA. ACM.

Kelly, D. (2009). Methods for evaluating interactive information retrieval systems with users. *Foundations and Trends in Information Retrieval*, 3(1-2):1–224.

Kelly, R., and Payne, S. J. (2013). Division of labour in collaborative information seeking: Current approaches and future directions. In *Proceedings of the International Workshop on Collaborative Information Seeking*, CSCW 2013, San Antonio, Texas, USA.

Kelly, R., and Payne, S. J. (2014). Collaborative web in search in context: A study of tool use in everyday tasks. In *Proceedings of the 17th ACM conference on Computer Supported Cooperative Work and Social Computing (CSCW '14),* pages 807–819. ACM, New York, NY, USA.

Kern, W. (2008). Web 2.0-end of accessibility? Analysis of most common problems with Web 2.0 based applications regarding Web accessibility. *International Journal of Public Information Systems*, *4*(2).

Kildal, J., and Brewster, S. A. (2006). Non-visual overviews of complex data sets. In *CHI'06 extended abstracts on Human factors in computing systems*, pages 947–952, New York, USA.

Kouroupetroglou, C., Salampasis, M., and Manitsaris, A. (2007). Browsing shortcuts as a means to improve information seeking of blind people in the WWW. *Universal Access in the Information Society*, *6*(3): 273–283.

Krishnappa, R. (2005). Multi-user search engine (muse): Supporting collaborative information seeking and retrieval. Technical Report. Information Science and Technology. Rolla, University of Missouri-Rolla.

Kuhlthau, C. C. (1991). Inside the search process: Information seeking from the user's perspective. *Journal of the American Society for Information Science*, *42*(5): 361–371.

Kules, B., and Capra, R. (2008). Creating exploratory tasks for a faceted search interface. In *Proceedings of the Second Workshop on Human-Computer Interaction and Information Retrieval*, pages 18-21. Redmond, WA, USA.

Lang, T. (2003). Comparing website accessibility evaluation methods and learnings from usability evaluation methods. *Peak Usability*.

Large, A., Beheshti, J., and Rahman, T. (2002). Gender differences in collaborative Web searching behavior: an elementary school study. *Information Processing and Management*, *38*(3): 427–443.

Lazar, J., Feng, J., and Allen, A. (2006). Determining the impact of computer frustration on the mood of blind users browsing the web. In *Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility* (Assets '06), pages149–156. New York, NY, USA. ACM.

Lazar, J., Allen, A., Kleinman, J., and Malarkey, C. (2007). What Frustrates Screen Reader Users on the Web: A Study of 100 Blind Users. *International Journal of Human-Computer Interaction*, *22*(3): 247–269.

Lewis, C. (1982). *Using the "thinking-aloud" method in cognitive interface design*. IBM TJ Watson Research Center.

Lewis, J. R. (1995). IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use. *International Journal of Human-Computer Interaction*, 7(1):57-58.

Liechti, O., and Sumi, Y. (2002). Editorial: Awareness and the WWW. *International Journal of Human Computer Studies*, *56*(1): 1–6.

Linden, G., Smith, B., and York, J. (2003). Amazon.com recommendations: item-to-item collaborative filtering. *Internet Computing, IEEE*, *7*(1): 76 – 80.

London, S. (1995). Collaboration and community. *Richmond, VA, Pew Partnership for Civic Change, University of Richmond*. Retrieved July 2013 from: http://www.upperskeena.ca/storytellers/CCL%20research/ccl/themes/micro-macro/collaboration.pdf

Lopes, R., Van Isacker, K., and Carriço, L. (2010). Redefining assumptions: accessibility and its stakeholders. In *Computers Helping People with Special Needs*, pages 561–568. Springer.

MacKenzie, I. S. (2013). *Human-Computer Interaction: An Empirical Research Perspective*. Amsterdam: Morgan Kaufmann.

Makri, S., Blandford, A., and Cox, A. L. (2008). Investigating the information-seeking behaviour of academic lawyers: From ellis's model to design. *Information Processing and Management*, 44(2):613–634.

Malone, T. W. (1983). How do people organize their desks?: Implications for the design of office information systems. *ACM Trans. Inf. Syst.*, *1*(1), 99–112. doi:10.1145/357423.357430

Mankoff, J., Fait, H., and Tran, T. (2005). Is your webpage accessible?: a comparative study of methods for assessing webpage accessibility for the blind. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '05)*, pages 41–5., New York, NY, USA. ACM.

Marchionini, G. (1997). *Information seeking in electronic environments*. Cambridge University Press. New York, USA

Marchionini, G. (2006). Exploratory search: from finding to understanding. *Commun. ACM*, *49*(4): 41–46.

Marchionini, G., Geisler, G., and Brunk, B. (2000). Agileviews: A human-centered framework for interfaces to information spaces. In *Proceedings of the Annual Conference of the American Society for Information Science*. Chicago, IL, USA.

Marchionini, G., and White, R. (2008). Find what you need, understand what you find. *International Journal of Human Computer Interaction*, *23*(3): 205–237.

McGookin, D., and Brewster, S. (2007). An initial investigation into non-visual computer supported *collaboration*. In *Proceedings CHI'07 extended abstracts on Human factors in computing systems*, *pages* 2573–2578, San Jose, CA, USA.

Meiselwitz, G., Wentz, B., and Lazer, J. (2010). Universal Usability: Past, Present, and Future. *Foundations and Trends® in Human–Computer Interaction*, *3*(4): 213–333.

Metatla, O., (2010). *Collaborating Through Sounds: Audio-Only Interaction with Diagrams*. PhD Thesis, Queen Mary University of London, London, United Kingdom.

Metatla, O., Bryan-Kinns, N., and Stockman, T. (2008). Constructing relational diagrams in audio: the multiple perspective hierarchical approach. In *Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility,* pages 97–104, Nova Scotia, Canada.

Metatla, O., Bryan-Kinns, N., Stockman, T., and Martin, F. (2011). Designing for collaborative cross-modal interaction. In *Proceedings. of Digital Engagement 2011 the 2nd RCUK Digital Economy All Hands* Meeting, Newcastle, UK.

Metatla O., Bryan-Kinns N., Stockman T., Martin F., (2012) Cross-modal Collaborative Interaction Between Visually-impaired and Sighted Users in the Workplace. In *Proceedings of the International Conference of Auditory Display* (ICAD'2012), Georgia Institute of Technology, Atlanta, GA, USA.

Mikowski, M., and Powell, J. (2013). *Single Page Web Applications: JavaScript end-to-end* (1st edition). Shelter Island, NY: Manning Publications.

Moreno, L., Martínez, P., and Ruiz, B. (2008). Guiding accessibility issues in the design of websites. In *Proceedings of the 26th annual ACM international conference on Design of communication*, pages 65–72. New York, NY, USA: ACM.

Morris, M. R. (2008). A survey of collaborative web search practices. In *Proceedings of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, CHI ’08 (pp. 1657–*1660).* New York, NY, USA. ACM.

Morris, M. R. (2013). Collaborative search revisited. In *Proceedings of the 2013 conference on Computer supported cooperative work* . pages1181–1192. New York, NY, USA. ACM.

Morris, M. R., and Horvitz, E. (2007a). SearchTogether: an interface for collaborative web search. In *Proceedings of the 20th annual ACM* symposium on User interface software and technology. pages 3–12, Newport, RI, USA.

Morris, M., and Horvitz, E. (2007b). S3: Storable, Shareable Search. In C. Baranauskas, P. Palanque, J. Abascal, and S. Barbosa, Editors, *Human-Computer Interaction – INTERACT 2007*, Lecture Notes in Computer Science. Springer. 4662: 120–123.

Morris, M. R., Lombardo, J., and Wigdor, D. (2010a). WeSearch: supporting collaborative search and sensemaking on a tabletop display. In *Proceedings of the 2010 ACM conference on Computer supported cooperative work* (CSCW ’10). pages 401–410. New York, NY, USA: ACM.

Morris, M. R., Morris, D., and Winograd, T. (2004). Individual audio channels with single display groupware: effects on communication and task strategy. In *Proceedings of the 2004 ACM conference on Computer supported cooperative work.* pages 242–251. New York, NY, USA.

Morris, M. R., Paepcke, A., and Winograd, T. (2006). TeamSearch: comparing techniques for co-present collaborative search of digital media. In *Proceedings of First IEEE International Workshop on Horizontal Interactive Human-Computer Systems Tabletop*, pages 97–104, Adelaide, Australia.

Morris, M. R., and Teevan, J. (2010). *Collaborative Search: Who, What, Where, When, Why, and How*. Morgan and Claypool Publishers.

Morris, M. R., Teevan, J., and Bush, S. (2008). Enhancing collaborative web search with personalization: groupization, smart splitting, and group hit-highlighting. In *Proceedings of the 2008 ACM conference on Computer supported cooperative work* (CSCW ’08), pages 481–484. New York, NY, USA: ACM

Morris, M. R., Teevan, J., and Panovich, K. (2010b). What do people ask their social networks, and why?: a survey study of status message qanda behaviour. In *Proceedings of the 28th international conference on Human factors in computing systems* (CHI '10), pages 1739–1748. New York, NY, USA: ACM.

Muller-Tomfelde, C., and Steiner, S. (2001). Audio-enhanced collaboration at an interactive electronic whiteboard. In *Proceedings of the 7th International Conference on Auditory Display (ICAD)*, Espoo, Finland.

Murphy, E., Kuber, R., McAllister, G., Strain, P., and Yu, W. (2007a). An empirical investigation into the difficulties experienced by visually impaired internet users. Universal Access in the Information Society, 7(1-2):79–91.

Murphy, E., Kuber, R., Strain, P., McAllister, G., and Yu, W. (2007b). Developing sounds for a multimodal interface: conveying spatial information to visually impaired web users. In *Proceedings of the International Conference on Auditory Display (ICAD)*, pages 26–29, Montréal, Canada.

Mynatt, E. D. (1995). Transforming graphical interfaces into auditory interfaces. *Conference companion on Human factors in computing systems*, CHI '95 (pp. 67–68). New York, NY, USA: ACM.

Mynatt, E. D., and Weber, G. (1994). Nonvisual presentation of graphical user interfaces: contrasting two approaches. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 166–172. New York, US. ACM.

Neale, D. C., Carroll, J. M., and Rosson, M. B. (2004). Evaluating computer-supported cooperative work: models and frameworks. In *Proceedings of the 2004 ACM conference on Computer supported cooperative work*, pages 112–121. New York, USA. ACM.

Newell, A. F., Gregor, P., Morgan, M., Pullin, G., and Macaulay, C. (2011). User-sensitive inclusive design. *Universal Access in the Information Society, 10*(3):235–243.

Nickerson, L. V., and Stockman, T. (2005). Sonically Exposing the Desktop Space to Non-Visual Users: an Experiment in Overview Information Presentation. In *Proceeding of the Eleventh Meeting of the International Conference on Auditory Display (ICAD)*. Limerick, Ireland.

Nielsen, J. (1994). Enhancing the explanatory power of usability heuristics. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, pages 152–158. New York, USA. ACM.

Nielsen, J. (2007). *Breadcrumb navigation increasingly useful (2007)*. Retrieved June 2013 from: http://www.nngroup.com/articles/breadcrumb-navigation-useful/

Nielsen, J., and Molich, R. (1990). Heuristic evaluation of user interfaces. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 249–256. New York, USA. ACM.

O'Day, V. L., and Jeffries, R. (1993). Information artisans: patterns of result sharing by information searchers. In *Proceedings of the conference on Organizational computing systems (COCS '93), pages* 98–107. New York, NY, USA.

O'reilly, T. (2007). What is Web 2.0: Design patterns and business models for the next generation of software. *Communications and Strategies*, (1):17.

Olson, G. M., Olson, J. S., Carter, M. R., and Storrosten, M. (1992). Small group design meetings: An analysis of collaboration. *Human–Computer Interaction*, *7*(4): 347–374.

Otter, M., and Johnson, H. (2000). Lost in hyperspace: metrics and mental models. *Interacting with Computers*, *13*(1):1–40.

Paciello, M. G. (2000). *Web accessibility for people with disabilities*. CMP.

Paddison, C., and Englefield, P. (2003). Applying heuristics to perform a rigorous accessibility inspection in a commercial context. In *Proceeding of ACM SIGCAPH Computers and the Physically Handicapped*, pages. 126–133. ACM.

Parente, P. (2003). Audio enriched links: webpage previews for blind users. *ACM SIGACCESS Accessibility and Computing*: (77-78), 2–8.

Paul, S., (2009). *Understanding together: sensemaking in collaborative information seeking*. PhD Thesis, The Pennsylvania State University, Pennsylvania, USA.

Paul, S. A., and Morris, M. R. (2009). CoSense: enhancing sensemaking for collaborative web search. In *Proceedings of the 27th international conference on Human factors in computing systems* (CHI '09), pages 1771–1780. New York, NY, USA. ACM.

Paul, S. A., and Morris, M. R. (2011). Sensemaking in collaborative web search. *Human–Computer Interaction*, *26*(1-2), 72–122.

Peres, S. C., Best, V., Brock, D., Frauenberger, C., Hermann, T., Neuhoff, J. G., … Stockman, A. (2008). Auditory interfaces. *HCI beyond the GUI: Design for Haptic, Speech, Olfactory, and Other Nontraditional Interfaces*, 147–195.

Petrie, H., and Kheir, O. (2007). The relationship between accessibility and usability of websites. In *Proceedings of the SIGCHI conference on Human factors in computing system,* pages 397–406. ACM.

Petrucci, L. S., Harth, E., Roth, P., André, A., and Pun, T. (2000). WebSound: a generic Web sonification tool allowing HCI researchers to dynamically create new access modalities. In *Proceeding* of *CHI'00 extended abstracts on Human factors in computing systems,* pages 295–296, The Hague, Netherlands.

Pickens, J. and Golovchinsky, G. (2007). Collaborative Exploratory Search. *In Proceedings of Workshop on Human-Computer Interaction and Information Retrieval*, pages 21-22, MIT CSAIL, Cambridge, Massachusetts, USA.

Pickens, J., Golovchinsky, G., Shah, C., Qvarfordt, P., and Back, M. (2008). Algorithmic mediation for collaborative exploratory search. In *Proceedings of the 31st annual international ACM SIGIR conference on Research and development in information retrieval*, SIGIR '08, pages 315–322. New York, NY, USA: ACM.

Pirolli, P., and Card, S. (1995). Information foraging in information access environments. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (CHI '95), pages 51–58, New York, NY, USA. ACM.

Plimmer, B., Crossan, A., Brewster, S. A., and Blagojevic, R. (2008). Multimodal collaborative handwriting training for visually-impaired people. In *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems, pages* 393–402, Florence, Italy.

Poltrock, S., Grudin, J., Dumais, S., Fidel, R., Bruce, H., and Pejtersen, A. M. (2003). Information seeking and sharing in design teams. In *Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work*, pages 239–247.New York, USA. ACM.

Poltrock, S., and Handel, M. (2009). Modeling Collaborative Behavior: Foundations for Collaboration Technologies, In *Proceeding of 42nd Hawaii International Conference on System Sciences* (*HICSS '09),* pages 1-10 ,. Big Island, HI, USA.

Power, C., Freire, A., Petrie, H., and Swallow, D. (2012). Guidelines are only half of the story: accessibility problems encountered by blind users on the web. In *Proceedings of the SIGCHI conference on human factors in computing systems.* pages 433–442. ACM.

Qu, Y. (2003). A sensemaking-supporting information gathering system. In *Proceeding of CHI'03 extended abstracts on Human factors in computing systems,* pages 906–907. Ft. Lauderdale, FL, USA.ACM.

Reddy, M. C. and Jansen, B. J. (2008). A model for understanding collaborative information behavior in context: a study of two healthcare teams. *Information Processing and Management*, 44(1):256-273.

Rodden, T. (1991). A survey of CSCW systems. *Interacting with Computers*, *3*(3): 319–353.

Rogers, Y; Sharp, H; Preece, J; (2011) Interaction Design: Beyond Human-Computer Interaction. (3rd ed.). John Wiley.

Russell-Rose, T., & Tate, T. (2012). Designing the search experience: The information architecture of discovery. Newnes.

Rutter, R., Lauke, P. H., Waddell, C., Thatcher, J., Henry, S. L., Lawson, B., others. (2006). *Web accessibility: Web standards and regulatory compliance*. Springer.

Sahib, N. G., Tombros, A., and Stockman, T. (2012). A comparative analysis of the information-seeking behavior of visually impaired and sighted searchers. *Journal of the American Society for Information Science and Technology*.

Sahib, N. G., Tombros, A., and Stockman, T. (2014). Investigating the behavior of visually impaired users for multi-session search tasks. *Journal of the American Society for Information Science and Technology, 65*(1): 69–83.

Sahib, N. G., Tombros, A., and Stockman, T. (2015). Evaluating a search interface for visually impaired searchers. *Journal of the Association for Information Science and Technology*.

Sahib, N. G., Stockman, T., Tombros, A., and Metatla, O. (2013). Participatory Design with Blind Users: A Scenario-Based Approach. In *Human-Computer Interaction–INTERACT 2013*, pages 685–701. Springer.

Salton, G., and Buckley, C. (1997). Improving retrieval performance by relevance feedback. *Readings in information retrieval, 24*:5.

Sears, A. (1997). Heuristic walkthroughs: Finding the problems without the noise. *International Journal of Human-Computer Interaction*, *9*(3):213–234.

Shah, C. (2009). Toward Collaborative Information Seeking (CIS). In Proceedings of JCDL Workshop on Collaborative Exploratory Search, Pittsburgh, PA, USA.

Shah, C. (2010a). Coagmento-a collaborative information seeking, synthesis and sense-making framework. *Integrated Demo at CSCW 2010,* Savannah, GA, USA.

Shah, C. (2010b). Working in Collaboration-What, Why, and How. In *Proceedings of Collaborative Information Retrieval workshop at CSCW 2010*. Savannah, GA, USA.

Shah, C (2012). *Collaborative Information Seeking: The Art and Science of Making the Whole Greater than the Sum of All*. The Information Retrieval Series, Vol. 34. Springer.

Shah, C. (2013a). Effects of awareness on coordination in collaborative information seeking. *Journal of the American Society for Information Science and Technology, 64*(6): 1122–1143.

Shah, C. (2013b). *Collaborative information seeking (CIS): Challenges and opportunities*. In *Proceedings of the Third Workshop on Collaborative Information Seeking at CSCW 2013 Conference*, San Antonio, TX, USA.

Shah, C. (2014). Evaluating collaborative information seeking–synthesis, suggestions, and structure. *Journal of Information Science*.

Shah, C., and González-Ibáñez, R. (2010). Exploring information seeking processes in collaborative search tasks. *In Proceeding of the American Society for Information Science and Technology*, 47(1): 1–7.

Shah, C., and González-Ibáñez, R. (2011). Evaluating the synergic effect of collaboration in information seeking. In *Proceedings of the 34th international ACM SIGIR conference on Research and development in Information Retrieval,* pages 913–922, New York, USA.

Shah, C., and Marchionini, G. (2010). Awareness in collaborative information seeking. *Journal of the American Society for Information Science and Technology*, *61*(10): 1970–1986.

Sharples, M. (1993). Adding a little structure to collaborative writing. In Diaper, D. and Sanger, C., Editors, *CSCW in Practice: An Introduction and Case Studies*, pages (51–68*)*. Springer.

Shneiderman, B. (1996). The eyes have it: A task by data type taxonomy for information visualizations., In *Proceedings of IEEE Symposium on Visual Languages*, pages *336–343.* Boulder, CO, USA.

Shneiderman, B. (2000). Universal usability. *Communications of the ACM*, *43*(5):84–91.

Shneiderman, B., Byrd, D., and Croft, W. B. (1998). Sorting out searching: A user-interface framework for text searches. *Communications of the ACM*, 41(4): 95–98.

Shneiderman, B., and Plaisant, C. (2004). *Designing the User Interface: Strategies for Effective Human-Computer Interaction (4th ed.). Pearson.*

Shum, H. Y., and Connell, D. L. (2012). *Multi-pane presentation of multidimensional search results*. Google Patents.

Skitka, L. J., and Sargis, E. G. (2005). Social psychological research and the Internet: the promise and peril of a new methodological frontier. *The Social Net: The Social Psychology of the Internet*, 1–26.

Sloan, David, Heath, A., Hamilton, F., Kelly, B., Petrie, H., and Phipps, L. (2006). Contextual web accessibility - maximizing the benefit of accessibility guidelines. In *Proceedings of the 2006 international cross-disciplinary workshop on Web accessibility (W4A): Building the mobile web: rediscovering accessibility?* (W4A '06), pages 121–131). New York, NY, USA: ACM.

Smeaton, A. F., Lee, H., Foley, C., and McGivney, S. (2007). Collaborative video searching on a tabletop. *Multimedia Systems*, *12*(4-5), 375–391.

Smeaton, A. F., Lee, H., Foley, C., McGivney, S., and Gurrin, C (2006). Físchlár-diamondtouch: Collaborative video searching on a table. *In Proceeding of Multimedia Content Analysis, Management, and Retrieval*, San Jose, CA, USA.

Smith, A., Brenner, J., (2012). *Twitter Use 2012. Pew Internet Project.* Retrieved October 2013 from: http://pewinternet.org/Reports/2012/Twitter-Use-2012.aspx

Smith, I., and Hudson, S. E. (1995). Low disturbance audio for awareness and privacy in media space applications. In *Proceedings of the third ACM international conference on Multimedia*, pages 91–97. San Francisco, CA, USA.

Smyth, B., Balfe, E., Boydell, O., Bradley, K., Briggs, P., Coyle, M., and Freyne, J. (2005). A live-user evaluation of collaborative web search. In *Proceedings of the Nineteenth International Joint Conference on Artificial Intelligence.* pages 1419–1424. San Francisco, USA.

Smyth, B., Briggs, P., Coyle, M., and O'Mahony, M. (2009). Google Shared. A Case-Study in Social Search. In G.-J. Houben, G. McCalla, F. Pianesi, and M. Zancanaro, Editors, *User Modeling, Adaptation, and Personalization, Lecture Notes in Computer Science (*5535): 283–294, Springer.

Steen-Hansen, L., & Fagernes, S. (2015). Achieving Accessible Rich Internet Applications. *Norsk Informatikkonferanse (NIK).* Retrieved from: http://ojs.bibsys.no/index.php/NIK/article/view/251

Stockman, T., and Metatla, O. (2008). The influence of screen readers on web cognition. *Proceedings of Accessible design in the digital world conference (ADDW 2008), York, United Kingdom.*

Stockman, T., and Nickerson, L. V. (2013). Towards An agenda for Auditory Overviews. In *Proceedings of ISon 2013, 4th interactive Sonification Workshop*, Fraunhofer IIS, Erlangen, Germany.

Suchman, L. A. (1987). *Plans and situated actions: The problem of human-computer communication*. Cambridge University Press, New York.

Susini, P., Vieillard, S., Deruty, E., Smith, B. and Marin, C. (2002) Sound Navigation: Sonified Hyperlinks. *Proceedings of the International Conference on Auditory Display(ICAD2002), kayoto, Japan.*

Sutcliffe, A., and Ennis, M. (1998). Towards a cognitive theory of information retrieval. *Interacting with Computers,* 10(3): 321–351.

Takagi, H., Saito, S., Fukuda, K., and Asakawa, C. (2007). Analysis of Navigability of Web Applications for Improving Blind Usability. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 14(3).

Tao, Y., and Tombros, A. (2013). An exploratory study of sensemaking in collaborative information seeking. In *Advances in Information Retrieval*, pages 26–37. Springer.

Tao, Y., and Tombros, A. (2014). Investigating Collaborative Sensemaking Behavior in collaborative Information Seeking. *Computer*, (3), 38–45.

Taylor, R. S. (1968). *Question-negotiation an Information-Seeking in Libraries. College and Research Libraries,* 29(3):178-194.

Teevan, J. (2007). The research engine: simultaneous support for finding and re-finding. *Proceedings of the 20th annual ACM symposium on User interface software and technology, UIST ’07,* pages 23–32. New York, NY, USA: ACM.

Teevan, J., Alvarado, C., Ackerman, M. S., and Karger, D. R. (2004). The perfect search engine is not enough: a study of orienteering behavior in directed search. In *Proceedings of the SIGCHI conference on Human factors in computing systems (CHI ’04),* pages 415–422. New York, NY, USA. ACM.

Teevan, J., Morris, M. R., and Azenkot, S. (2014). Supporting interpersonal interaction during collaborative mobile search. *Computer*, (3), 54–57.

Teevan, J., Morris, M. R., and Bush, S. (2009). Discovering and using groups to improve personalized search. In *Proceedings of the Second ACM International Conference on Web Search and Data Mining (WSDM ’09), pages 15–24. New York, NY, USA. ACM.*

Teevan, J., Ramage, D., and Morris, M. R. (2011). #TwitterSearch: a comparison of microblog search and web search. *Proceedings of the fourth ACM international conference on Web search and data mining, WSDM ’11,* pages 35–44. New York, NY, USA: ACM.

Thatcher, J., Waddell, C. and Burks, M. (2003). *Constructing accessible websites. APress.*

Treviranus, Jutta. (2008). Authoring Tools. In S. In Harper and Y. Yesilada, Editors, *Web Accessibility*, pages 127-138. London: Springer London.

Turner, T., Qvarfordt, P., Biehl, J. T., Golovchinsky, G., and Back, M. (2010). Exploring the workplace communication ecology. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 841–850, Atlanta, USA.

Twidale, M., Nichols, D., and Paice, C. (1997) Browsing is a Collaborative Process. *Information Processing and Management,* 33(6):761-783.

Vigo, M., Brown, J., and Conway, V. (2013). Benchmarking web accessibility evaluation tools: measuring the harm of sole reliance on automated tests. In *Proceedings of the 10th International Cross-Disciplinary Conference on Web Accessibility*, New York, USA. ACM.

Vigo, M., and Harper, S. (2013). Coping tactics employed by visually disabled users on the web. *International Journal of Human-Computer Studies*, *71*(11):1013–1025.

Vigo, M., Kobsa, A., Arrue, M., and Abascal, J. (2007). User-tailored web accessibility evaluations. In *Proceedings of the eighteenth conference on Hypertext and hypermedia*, pages 95–104. New York, USA. ACM.

Walker, B.N., Nance, A., and Lindsay, J. (2006) "Spearcons: Speech-based earcons improve navigation performance in auditory menus," In *Proceedings of the International Conference on Auditory Display (ICAD)*, London, U.K.

Watson, D., Clark, L. A., and Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, *54*(6):1063.

WebAIM Survey (2014). Screen reader user survey #5 results. Retrieved March 2014 from http://webaim.org/projects/screenreadersurvey5/

Wells, A.T. and Rainie, L (2008). The Internet as Social Ally. *First Monday, 13(11)*.

Wells, G. (1999). *Dialogic inquiry: Towards a socio-cultural practice and theory of education*. Cambridge University Press.

Wilson, T. D. (1981). On user studies and information needs. *Journal of documentation, 37(1):3–15*.

Wilson, T. D. (1999). Models in information behaviour research. *Journal of documentation, 55(3): 249–270*.

Wilson, S., and Maclean, R. (2010). Research Methods and Data Analysis for Psychology. *McGraw-Hill Higher Education.*

Wilson, M. L., and schraefel, m c. (2009). Evaluating Collaborative Search Interfaces with Information Seeking Theory. In *Proceeding of Workshop on Collaborative Information Retrieval*, Pittsburgh, PA, USA.

Winberg, F. (2006). Supporting cross-modal collaboration: Adding a social dimension to accessibility. *Haptic and Audio Interaction Design, 102–110.*

Wu, D., and Yu, W. (2015). Undergraduates' Team Work Strategies in Writing Research Proposals. In *Proceedings of the 18th ACM Conference Companion on Computer Supported Cooperative Work and Social Computing,* pages 199–202. New York, NY, USA: ACM.

Yesilada, Y., Brajnik, G., and Harper, S. (2009a). A Barrier Walkthrough Study with Expert and Non-Expert Judges. University of Manchester.

Yesilada, Y., Brajnik, G., and Harper, S. (2009b). How Much Does Expertise Matter?. In *Proceeding of the 11th international ACM SIGACCESS conference on Computers and accessibility* (*Assets '09),* pages 203–210, New York, USA. ACM.

Zajicek, M., Powell, C., and Reeves, C. (1998). A Web navigation tool for the blind. In *Proceedings of the third international ACM conference on Assistive technologies,* pages 204–206, New York, USA. ACM.

Zhao, H. (2006). *Interactive sonification of abstract data: framework, design space, evaluation, and user tool*. PhD thesis, University of Maryland at College Park, College Park, MD, USA.

Zhao, H., Plaisant, C., Shneiderman, B., and Duraiswami, R. (2004). Sonification of geo-referenced data for auditory information seeking: Design principle and pilot study. In *Proceedings of the International Conference on Auditory Display (ICAD),* Sydney, Australia.

Appendices

Appendix A. Preliminary Survey

This appendix contains the questions in the preliminary survey discussed in Chapter 4.

<u>Section 1: General Questions (1 of 2)</u>

1. Age Range:
   - o 17 or younger
   - o 18-20
   - o 21-29
   - o 30-39
   - o 40-49
   - o 50-59
   - o 60 or older
2. Gender
   - o Male
   - o Female
3. Occupation
   - o Student
   - o Employed
   - o Unemployed

If You chose 'Employed' in Question (3) Please, specify your job title?

How long have you have been employed?

- o Less than 6 months
- o 6 months to 1 year

- 1 to 2 years
- 2-5 years
- More than 5 years

4. Qualification
    - GCSE’s and A-levels obtained
    - Undergraduate
    - Postgraduate or higher Degree
5. What Assistive technology you use
    - None.
    - Screen Reader
    - braille display,
    - screen magnifier software
    - Others, Please Specify_______________________________________

Section 2: Collaborative Search (2 of 2)

6. Do you ever work together with other people to search the web?
    - Yes
    - No

    If your answer is No, Please, go to question 21
7. When you work together with other people, state whether the people you work with are
    - Sighted
    - Visually impaired
    - Both
8. Do the people you search the web with you use the same assistive technology as you?

- Yes
- No

Please state what assistive technology they use_________________

9. How often do you work together with sighted or (VI) people to search the web?
    - daily
    - Once Weekly
    - At least once a month
    - At least once in the past six months
10. How do you divide the work?
    - We divide the responsibilities before starting the search
    - We work together and discuss as we go along processing the results as we go
11. What methods do you use to help you work together during search activity?
    - We sit together in the same place.
    - We use Voice call.
    - We use instant messaging.
    - We use email.
    - We create a shared document into which we enter shared results
    - We print out the results in Braille and Print.
    - Other (Please Specify)_____________________________
12. What sort of task do you carry out when work together in a web search?
    - Personal (Planning a Trip, Shopping tasks, medical information, Real estate).
    - Business/Work related (Literature Search, fact finding, event organizing).
    - Other (Please Specify)____

13. How do you usually manage your search results?

- Take Note using note pad during the search process.
- Pasting Links into a document/personal website.
- Use Bookmark or favourite functionality in web browser.
- Save Webpages to a folder on the computer.
- Printing Webpage.
- Email links to myself.

Other (please Specify)_________________

Appendix B. Materials for Study 1

This appendix contains materials from the exploratory observational study described in Chapter 5 to investigate the CCIS behaviour between VI and sighted users. It includes an the information sheet given to participants prior to the study, the consent form used, the pre-study demographic questions, examples of the collaborative search tasks and the questions used in the semi-structured interview carried out after each observation. This appendix also includes a guide to conducting the scenario-based interview which consist of the descriptions of each scenario followed by the questions to be asked.

B.1 Participants Information Sheet and Consent Form

1. Queen Mary University of London

Information Sheet for Participants

Research study [Cross-modal Collaborative Information Seeking]: Information for participant

We would like to invite you to be part of this research project, if you would like to. You should only agree to take part if you want to; it is entirely up to you. If you choose not to take part there won't be any disadvantages for you and you will hear no more about it. Please read the following information carefully before you decide to take part; this will tell you why the research is being done and what you will be asked to do if you take part. Please ask if there is anything that is not clear or if you would like more information. If you decide to take part you will be asked to sign the attached form to say that you agree. You are still free to withdraw at any time and without giving a reason.

The Study

The study is related to the under investigated area of accessible collaborative information seeking (CIS). In this study, we aim to observe the activity between sighted and visual impaired users when performing a web search activity together hence identifying the challenges faced and providing improved solutions for visually impaired users and sighted people to work together in finding and organising information jointly on the web. Ultimately this aims to contribute to the integration of visually impaired people in the work place

Your task

1. At the Beginning you will be asked to fill out a pre-experiment questionnaire that collect information about your use of search engines, your involvement is search activity with other people in additional to basic demographical data.
2. You will need to work with your partner to perform the tasks in the task sheet given to you. There will be two tasks. The first task you will be working with your experiment partner remotely. The second task you will be working with your parent in the same place.
3. Finally experimenter will conduct an interview with you and your partner in the study in which you will be asked questions regarding the task you performed during the observation.

The Researcher

- The researcher will firstly explain to you the purpose of the study.
- The researcher will then hand you the task sheet (in soft copy).
- The researcher will then observe, take notes about and video record the process and in about 35-40 minutes the research will ask you to stop the process.
- Finally you will be interviewed by the researcher about the task you just performed.

Your Rights

- You have the right to ask the researcher question at any point in the experiment.
- You have the right to refuse to answer any question.
- You have the right to stop the experiment at any time.
- You have the right to take a break from the experiment at any time.
- You have the right to refuse to do any given task.
- You have the right to withdraw at any time from participating in this study.
- You have the right to refuse to be recorded during the observation.

Risks or discomforts

No risks or discomforts are anticipated from taking part in this study.

Confidentiality

- The information you provide will be identified by number and we will insure that your name and any identifiable data will be kept in a safe place.
- Any use during the study of the data collected will be done anonymously.
- The data collected will ONLY be used for the purpose of this study. We guarantee that no data will be to third parties or used for other purposes
- All data collected will be kept until the research completed and then will be destroyed.
- The research will be under the property of the School of Electronic Engineering and Department of Computer Science at Queen Mary University of London.

Researcher Details

Student: Dena Al-Thani dat30@eecs.qmul.ac.uk

Supervisor: Dr. Tony Stockman tony.stockman@eecs.qmul.ac.uk

Interaction, Media, and Communication

School of Electronic Engineering and Computer Science,

Queen Mary, University of London.

Queen Mary
University of London

Consent form

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: **Cross-modal Collaborative Information Seeking Observational study**
Queen Mary Research Ethics Committee Ref: QMREC2012/27

- Thank you for considering taking part in this research. The person organizing the research must explain the project to you before you agree to take part.
- If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.
- *I understand that if I decide at any other time during the research that I no longer wish to participate in this project, I can notify the researchers involved and be withdrawn from it immediately.*
- *I consent to the processing of my personal information for the purposes of this research study. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.*

Participant's Statement:

I ____ agree that the research project named above has been explained to me to my satisfaction and I agree to take part in the study. I have read both the notes written above and the Information Sheet about the project, and understand what the research study involves.

Signed: Date:

Investigator's Statement:

I ____ confirm that I have carefully explained the nature, demands and any foreseeable risks (where applicable) of the proposed research to the volunteer

B.2 Pre-Study Questionnaire

Please, place an 'X' in front of the chosen answer

1. Which category below includes your age?
    - o 18-20
    - o 21-29
    - o 30-39
    - o 40-49
    - o 50-59
    - o 60 or Older
2. Gender
    - o Male
    - o Female
3. Occupation
    - o Student
    - o Employed
    - o Unemployed
4. If 'Employed', please Specify Job Title or If 'Student', Please state your course title
5. How long have you been employed

- Less than 6months
- 6months to 1 year
- 1 to 5 years
- More than 5 years

6. Qualifications
    - GCSE and A-Level
    - Undergraduate
    - Postgraduate or Higher Degree
7. Please, state the name of your last degree?
8. Please indicate your Level of visual impairment (if any)
    - Fully sighted
    - Partially sighted
    - Blind
9. What Assistive Technology you use (Please, check all that apply)
    - None
    - Screen reader
    - Braille display
    - Screen magnifier software
    - Others (Please, specify)

10. Please, state which web browser do you use?

- Internet Explorer
- Firefox
- Safari
- Other (Please specify)

11. Please, state which search engine do you regularly use?

- Google
- Yahoo
- Bing
- Other (Please specify)

12. How long have you been using this search engine?

- Less than a year
- From 1 to 5 years
- More than 5 years

13. How do you usually manage your search results that you want to get back to later on? (Please, Check all that applies)

- Bookmarks and favourite functionality in web browser
- Save webpage to a folder on the computer
- Take notes using a note taking package
- Pasting link into a document/personal website

- Emil links to myself
- Printing webpages
- Others (Please, specify)

14. Have you ever worked with your partner in this experiment?
    - Yes
    - No
15. If answered ‘Yes’ in previous question, please state for how long you have been working with him/her?
16. If you work together please state whether you
    - Report to your experiment partner
    - Your experiment partner reports to you
    - You are colleagues
17. How often do you work with other people to search the web?
    - Never
    - Daily
    - Once Weekly
    - At least once a month
    - At least once in the past six months.
18. Can you give example of information you searched in the web with other people

B.3 Collaborative Search Tasks

Example Task (performed in the Pilot Study)

You were asked to organize a seminar which includes a speaker. The seminar will take place two weeks' time from now at 5pm. The speaker will arrive a day before the seminar and will leave after the seminar. About 40 people are expected to attend it. Your tasks are: (1) finding a venue (2) finding a catering service (tea, coffee and sandwiches) (3) booking a one night hotel for the speaker, hotel should near the chosen venue and the night price rate should not exceed 95£. The event should take place near your work place.

Task 1:

Your first task which you need to perform individually for about 15 Minutes is to come up with three criteria of choosing the venues. These criteria might be the cost, the location or any other criteria you might think of. For each criteria you come with, you have to allocate two or more candidate venues that satisfy this criteria. Please, email me the criteria you had chosen but not the venues. You can store the information of this task in any format you want and bring them with you on the day of experiment, as you will be using them in the day of the experiment.

Please, also note that the venue needs to be close to your work place be appropriate for 40-50 people, i.e. large enough but not excessively large (i.e. 70 might be ok), and have all the facilities needed for a seminar to take place.

Task 2:

Now in the next 35 minutes, using the information you obtained in the first task chose with your partner the most suitable venue, find a catering service, and book a hotel for the speaker located near the venue you have chosen.

Example Tasks (performed in the rest of the sessions):

Co-located Condition

This summer, you, your partner in this session and two other colleagues are planning to attend a conference and Job fair in the United States. The Trip will involve visiting three cities, which are Las Vegas, Los Angles (LA) and Seattle. You will be staying two days in Las Vegas, one day in LA, and two days in Seattle. You will need to find the best way to travel between these three cities, book tickets and book hotels for all three cities.

The conference will take place in ARIA Resort - Las Vegas on 26st of July for two days. The second day of conference will only be a half day; you will need to organize an activity to do in the rest of the day. It might be attending a concert, a musical, a show, an exhibition or any sort of activity. You will need to book tickets in advance for this activity.

In LA, you will need to find a tourism site to visit and a place to dine in. You will also need to organize ways to travel from the hotel to both sites.

In Seattle, you will be taking part in a two day UK's University fair on the 30th of July and 31st of July based at Seattle University. On the first day you will be giving a presentation about facilities at the College for students with disabilities or learning difficulties. The presentation will start at 3pm and will last for 1 hour followed by a 30 minute Questions and Answers session. You will need to book a seminar room in the university for around 30-40 people. You will need to make sure that the venue has Internet access, a white board and data projector. In the evening from 7pm till 9pm, you will need to hold an evening reception for networking and informal discussions about the College and living in the UK, and that has to take place somewhere near the University. You will need book the venue and catering service as well. For the second day, you will need to book a room from 10am to 4pm in order to conduct the interviews with possible candidates.

In the next 35 minutes, organize this trip with your partner. Please, feel free to use any tool you wish in order to communicate with your experiment partner during this task. These tools maybe: email, instant messaging, shared documents or folders, or any tool that you find suitable.

Please, note you don't need to actually make the booking, but you need to take notes of all details about it including website, cost, date and timing, and any details that will help you both in making the actual booking later in time.

Distributed Condition

This summer, you, your partner in this session and two others are invited to attend a friend wedding in Australia. You will be visiting three cities there which are Sydney, Melbourne and Gold Cost. The wedding will be in Melbourne. You will be staying one day in Sydney, two days in Melbourne, and one day in Gold Cost. You will need to find the best way to travel between these three cities, book tickets and book hotels for all three cities.

You will be arriving in Sydney on morning of the 26th of September. You will need to organize an activity to do in the rest of the day and book tickets for it in advance. You will also need to choose a place to dine and book tickets for it too.

You will be travelling to Melbourne on the morning of the 27th of September. The wedding will take place on the 28th of September in Crown Plaza hotel. In Melbourne you would need to find a place that you can rent a tuxedo from. Additionally, you would need to arrange a sightseeing activity to do during the day before the wedding.

Your last destination is Gold Cost. You will travel on the morning of the 29th of September. In Gold Cost you and your friends will need to throw a party to your newlyweds friends. You will need to arrange for place, food and drinks, and music. The place should fit 15 to 20 guests. On the 30 of September, which is your last day you would need to arrange to find a tourism site for you to visit with your friends.

In the next 35 minutes, organize this trip with your partner. Please, feel free to use any tool you wish in order to communicate with your experiment partner during this task. These tools maybe: email, instant messaging, shared documents or folders, or any tool that you find suitable.

Please, note you don’t need to actually make the booking, but you need to take notes of all details about it including website, cost, date and timing, and any details that will help you both in making the actual booking later in time.

B.4 Post-Study Semi-structured Interview Questions

1. What sort of information you think it is important to keep about a website?
2. The reason you chose (a particular) tool/technique to store your information?
3. Have you ever experienced collaborative search? What tools did you use to communicate with your partner?
4. Do you remember the tasks you had? Do you think of any reason to collaborate?
5. Could you please, rate the overall performance of the whole task (10 Being the most satisfactory and 1 being the lest satisfactory)
6. At what stage you felt that it was hard to communicate with your partner?
7. Could you rate the communication lever (10 Being the most satisfactory and 1 being the lest satisfactory)
8. Do you think that there are better methods to communicate than the ones chosen?
9. How would you rate the making decision process?
10. How do you describe the process of sharing results and recommendations?
11. Did you find difficulties in instructing your partner to navigate to a certain content of a page?
12. Do you think sharing the same screen (e.g. the same search results) could be easier? Please explain why?

B.5 Scenario-based Interview

As part of your job, you are asked to work on a one year project in the University of Dubai, which is located in Dubai city in the United Arab Emirates (UAE). The project starts in October 2013 and you and your partner are planning to move there next September. You and your partner are searching for accommodation, transport services and things to do while you are there.

Please, take your time in reading each Scenario and Answering the Questions in Each Scenario.

Scenario A:

You are at the office and your partner is at home. Both of you are searching the web about accommodation in Dubai at the same time. You found an interesting website with several accommodation options. (1) How will you go about sharing the website with your partner In order for you to go through the options and discuss them together?

Your partner did not like these options and asked you to look for alternative websites while he/she is looking for transport services options available in Dubai. You went back to the search results page and found a number of websites that provided details of apartments for rent in Dubai which are quite close to the university. While your partner is busy in searching transport options, you needed to keep track of the websites found. (2)How will you keep track of the web sites you are visiting?

Let us assume that for some reason your partner has gone offline. (3) How will you be sharing these results with her/him?

Scenario B:

Hours later, when your partner is at home, you decide to search the web together to look for Guitar skills courses in Dubai. Each one of you is using his/her own computer; you started searching for classes. You found three different musical institutes in Dubai and you would like to discuss them with your partner. (4) Can you describe how you will go about discussing the websites found with your partner?

Scenario C:

While you will be in Dubai for almost a year, you thought of searching places to visit in Dubai to learn more about the culture and the history of the city. You found many websites of interesting museums, exhibitions, libraries and sites that you would love to visit while you are there.(5) Can you please describe the way you would keep track of these important websites to use them later on when you are in Dubai? (6) What is important to store about the websites?

Scenario D:

The process of looking for accommodation may be the longest process and may take several iterations. (7) Can you describe for me how you will be keeping track of interesting options found by you and your partner during these search iterations?

Let us assume you will be using a shared document that you and your partner will be updating with search results and interesting information (8) can you describe how you would go about organizing the document?

(9) Would you prefer your shared document to be an organized, structured document which contains the websites found categorised under a number of different headings, or for the document to be a simple list of the websites found? Explain the reasons for your preference?.

Appendix C. Materials for the Accessibility Review

This appendix contains the tasks conducted in the Barrier Walkthrough discussed in Chapter 7. C.1 contains the identified tasks. C2 includes the use cases scenario of each task and types of barriers encountered while performing it using the three screen readers. This is in addition further usability issues encountered and ways to overcome the dedicated barriers.

C.1 Barrier Walkthrough Tasks

A: Tasks related to login in process and activating the project

SearchTeam:

1. Task1: login
2. Task 2: Select CSpace

Coagmento:

3. Task 1: login
4. Task 2: Selecting project to work on

Diigo

5. Task 1: login
6. Task2: Select a Group

B: Tasks related to the results management process

SearchTeam:

1. Task 1: Creating a Folder
2. Task 2: Save a link to the folder.
3. Task 3: Add and View a comment to the link.
4. Task 4: Add a Post
5. Task 4: Rearranging posts order
6. Task 5: Moving post from one folder to another.

Coagmento:

7. Task 1: Save a Bookmark
8. Task 2: Save a Snippets
9. Task 3: Save and view a note.

Diigo:

10. Task 1: Save a bookmark
11. Task 2: Save a Topic
12. Task 3: Add a comment
13. Task 4: Filter Topics and bookmark

14. Task 5: like a topic or a bookmark

C: Tasks related to the individual information seeking process

SearchTeam:

1. Task1: Search for a Query Term

Coagmento:

2. Task1: Search for terms

Diigo:

3. Task 1: Search within group

D: Tasks related to the awareness aspect of the process:

SearchTeam:

1. Task 1: Send and receive a chat message.
2. Task 2: view recent activity panel
3. Task 3: view past search

Coagmento:

4. Task 1: Send and receive chat message.
5. Task 2: View history panel that includes snippets, bookmarks, searches and files.
6. Task 3: View notification panel.

Diigo:

7. Task 1: Enable email alert on a bookmark or topic

C.2 Tasks and Barriers Exercises

Task Number		Task Steps	Barriers detected using all three screen readers	Barriers detected using JAWS	Barriers detected using NVDA	Barriers detected using Voiceover	Problem listed
A:1	SearchTeam	1. On the home page, enter your username and password. 2. Click on login		IE No barriers Firefox No Barriers	IE No barriers Firefox No Barriers	Safari No Barriers	
A:2		1. From the webpage top menu, Chose the Dashboard 2. Select a Space by click on one of the available spaces under the My Spaces Tab		IE No barriers Firefox No Barriers	IE No barriers Firefox No Barriers	Safari No Barriers	
A:3	Coagmento	1. From Coagmento toolbar click on connect 2. The sidebar will appear 3. Enter username and password 4. Click on login button		Firefox: Unable to access tool bar using the default PC Cursor Outcome: The evaluator spent 23 minutes attempting to access the sidebar Solution:	Firefox: The user was unable to access using the default navigation way. Outcome: The user was unable to access.	In Firefox: The sidebar was inaccessible The outcome: The user was unable to enter the Sidebar to be able to access the username and password.	This issue is not a WCAG related as it not a web related issue. It is related to the accessibility of the browser toolbar.

				Using JAWS cursor[39] Or JAWS OCR[40] scanning engine with jaws 14 and up.	Therefore, after reviewing NVDA help document [41] users tried several navigation approaches. Solution: Using Object navigation.	Solution: No solution found to overcome this barrier	
A:4		1. Type http://www.coagmento.org/CSpace/workspace/index.php to the address bar 2. From the webpage top menu 3. Chose the project name from the drop-down menu 4. The select project will appear in the sidebar menu next to active project	1. Have images and object which has alternative text Barrie The user is unable to identify the project name drop-down menu Outcome: As the drop down menu has no description the VI evaluator was able to complete the task with the assistant from the	Common barrier	Common Barrier	Firefox Barrier Accessing dynamic menu The outcome: The evaluator spent 16 minutes chose the project from the dynamic menu; but failed to complete it this task. Due to the fact that dynamic menus are	BW, WCAG 1.0 and WCAG 2.0

[39] JAWS Cursor perform actions that would normally be done using the mouse

[40] Convenient OCR (Optical Character Recognition) enables you to access any image on the screen that includes text, or recognize all of the text in a PDF document. (JAWS Documentation)

[41] http://www.nvaccess.org/files/nvda/documentation/userGuide.html#toc29

			principle researcher.			inaccessible.	
A:5	**Diigo**	1. From the Diigo website https://www.diigo.com/ 2. Chose the login button from the top menu 3. Enter the username and password 4. Click on login		No barriers detected	No barriers detected	No barriers detected	
A:6		1. From the top menu, choose MyGroups 2. Then chose a group		No Barriers detected	No Barriers detected	No Barriers detected	
B:1	SearchTeam	1. From the tabs area, chose 'Add a Folder to your Project' tab 2. New modal dialogue box 3. Enter folder name and click on Save button	No Barriers detected	No Barriers detected	No Barriers detected	No Barriers detected	
B:2		1. After entering a search term	No Barriers detected	No Barriers detected	No Barriers	No Barriers detected	

		in search engine edit box 2. Click on search button 3. Next to each search result there a 'save' and 'hide' buttons 4. Click on 'save' button 5. A modal Dialogue box 6. Pick a folder by selecting the folder and clicking enter			detected		
B:3		1. Navigate to the designated folder 2. Click enter 3. Within a folder; navigate to a link 4. Below the saved link, you can view comments 5. Below the saved link and in the 'write a comments' edit box, type the comment 6. Click on 'comment' button	No Barriers detected	No Barriers detected	No Barriers detected	No Barriers detected	
B:4		1. Navigate to the designated	Common Barrier The form include two	In IE and Firefox	In IE and Firefox	Safari	

		folder 2. Click enter 3. Within a folder; click on add a post 4. A Modal dialogue box will appear 5. Navigate to the title text field and enter the title 6. Navigate to the post text field and enter the post content 7. Click on 'save' button	edit fields that are not labelled. Outcome: The evaluator was not able to know the purpose of each edit box. Solution: The principle researcher advised the VI evaluator that there are two edit fields to be filled: post tile and post body.	Barrier: JAWS Form mode doesn't turn on automatically. User assumes that the JAWS form mode is automatically turned on and thus used forms mode keys to navigate the form. Outcome: Any forms mode key will not give the expected results. Solution: The evaluator noticed that forms mode is not on and hence navigate using arrows	Common Barrier	Common Barrier	
B:5		1. Navigate to the designated folder 2. Drag and drop the post or link to rearrange the order.	SearchTeam don't support W3C ARIA that support it	Action was not performed	Action was not performed	Action was not performed	WCAG 2.0 Ensuring key controls to all functionalities
B:6		1. Navigate to the designated post 2. Navigate to the 'Move' link	No barriers detected	No barriers detected	No barriers detected	No barriers detected	

		and select it 3. A Modal dialogue box will appear 4. Pick a folder by selecting it and clicking enter.					
B:7	Coagmento	1. Navigate to Coagmento toolbar 2. Click on bookmark button 3. Fill-in the add a note text field 4. From the radio button select the of page 5. Click on 'save' button		Unable to access tool bar using the default PC Cursor Outcome: The evaluator spent 23 minutes attempting to access the sidebar Solution: Using JAWS cursor[42] Or JAWS OCR[43] scanning engine with jaws 14 and up. When accessed the evaluator did not encounter barriers	Firefox: As in Task A3, When accessed the evaluator did not encounter barriers when filling the form.	Firefox: No Barrier Using Firefox and Voiceover evaluator was able to access the toolbar. The evaluator was able to access the bookmark.	Same as A4

[42] JAWS Cursor perform actions that would normally be done using the mouse
[43] Convenient OCR (Optical Character Recognition) enables you to access any image on the screen that includes text, or recognize all of the text in a PDF document. (JAWS Documentation)

				when filling the form.			
B:8		1. Navigate to Coagmento toolbar 2. Click on snippet button 3. Fill-in the add a note text field 4. From the radio button select the of page 5. Click on 'save' button		As in B7.	As in B7.		Same as A4, B7
B:9		1. Navigate to the Notepad in Coagmento sidebar 2. Navigate to the shared To Save a note 3. In the Note test filed type the note 4. Click Save note To view a note: 3. After note text field, you will find a list of previously saved note 4. Click on a note to view it.	Barrier Forms objects such as text box has no label. Outcome: The evaluator cannot locate the edit text box Solution: The VI evaluator was advised by the principle researcher about the location of the edit box	Common barrier Outcome: Evaluator was able to add a note in 2:45 minutes	Common Barrier Barrier The evaluator was not able listen to the text typed in the text field Outcome: Evaluator was able to add a note in 6 Minutes	Firefox: The evaluator was unable to access Coagmento Sidebar.	BW, WCAG 1.0, WCAG 2.0 Alternative text

B: 10		1. Navigate to Diigo toolbar 2. click bookmark button 3. a Modal dialogue box will appear 4. fill-in the description and tags text field 5. click in (More Options) and select the "Share to a Group" checkbox 6. click on 'Save' to save the bookmark	Common Barrier: "Tag" edit box is not labelled.	Common barrier User cannot reach "More options" using form navigation command TAB Outcome: User unable to select "share to a group" option Solution: "More options" can be accessed when user navigate using the arrow keys.	Common barrier	Diigo inaccessible	BW, WCAG 1.0, WCAG 2.0 Alternative text
B:11		1. Within a Group, click on Topic Button 2. A form will appear, fil-in the Title, comment, Tags 3. And click on 'Post' button	No barrier detected	No barrier detected	No barrier detected	No barrier detected	
B:12	Diigo	1. Navigate to the designated topic or bookmark 2. Click on 'comments', a text filed will appear	The comment edit box has no label. Outcome: When evaluator clicked on comment link the	Common barrier	Common barrier	Common barrier	BW, WCAG 1.0, WCAG 2.0 Alternative text

		3. Type the comment and click 'Post'	focus moved to the edit box. Even though the edit box was not labelled the evaluator knew it's the correct edit box as the focus was moved automatically.				
B:13		1. Within a Group, navigate to the word 'filter' 2. Click on either "Topic" or "Bookmark"	No barrier detected	No barrier detected	No barrier detected	No barrier detected	
B:14		1. Within a Group, navigate to the designated topic 2. Click on the like link next to topic or bookmark		No barrier detected	No barrier detected	No barrier detected	
C:1	SearchTeam	1. Navigate to Search Tab, Click "Enter" 2. Navigate to search engine text field 3. Enter Query term and click on 'Search' Button	No barriers detected	No barriers detected	No barriers detected	No barriers detected	

C: 2	Coagmento	1. Within Coagmento CSpace webpage 2. Navigate to the search text filed and enter the search term	Dynamic changes to the search page are not render by screen readers. Outcome: The VI evaluator didn't notice the changes in the search results page while entering the query as they were not render by the screen readers	Common barrier	Common barrier	Common barrier	BW, WCAG 1.0, WCAG 2.0 Dynamic Changes
C: 3	Diigo	1. Within the select group page 2. Navigate to "search this group" and enter the search term		JAWS screen readers didn't read "Search this group" edit box label Outcome: The evaluator was not able to find it	No barriers	No Barriers	BW, WCAG 1.0, WCAG 2.0 Alternative text

D:1	SearchTeam	1. Navigate to 'Team Chat' Button 2. Click enter, for the Team Chat tool to appear on the screen 3. Navigate to the text field in the team chat tool to type the message 4. Click on "send a message" button, to send a message	It involve two steps: 1. Step 1: open the team chat form 2. Step 2: navigate to the team chat form Issue with Step2: Common Barrier: The team Chat opens in a form not within the webpage context but above it as a modal dialogue form. The user can only reach the team chat using a mouse. Outcome The evaluator was not able to reach it using navigational strategy. Solution: Evaluator searched for key word "search team" using CTRL+F command to be able to reach the team chat window.	The evaluator has no issues with step 1 With step 2, the evaluator encountered the common barrier. Common Barrier The outcome: A evaluator is able to send a message within 2 minutes	In step 1, NVDA did not read the 'team chat' graphic button label. The location of the graphic button was described to VI evaluator to help him allocate it. With step 2, the evaluator encountered the common barrier. The outcome: The evaluator is able to open it with 2 minutes	The evaluator used Web Rotor[44], to navigate to the team chat easily. The evaluator has not encounter any issues in step 1 and 2. The outcome: The evaluator is able to send a message within 2 minutes	BW, WCAG 1.0, WCAG 2.0 Alterative text Keyboard- trap

[44] The Web Rotor provides an easier way to navigate a webpage with VoiceOver using lists of headings, links, forms and other items on a webpage.

D:2		1. Navigate to Recent Activity Panel		No barriers	No barriers	No barriers	
D:3		1. Navigate to search tab, click enter 2. Next to the search button, the past search mouse-over object is located	Common barrier Dynamic Mouse-over menu	Dynamic Mouse-over menu Outcome: After 9 minutes the evaluator was able to access it. Solution: "past search" link can be accessed using spacebar.	The evaluator was unable to view the past searches	The evaluator was unable to view the past searches	BW, WCAG 1.0, WCAG 2.0 Mouse-event
D:4		1. Navigate to Coagmento Sidebar 2. Navigate to the Chat component 3. Click enter, to view the chat tool 4. Enter chat message, in the text field 5. Click on "Send" button		No Barriers detected	No Barriers detected	Sidebar not accessible	
D: 5	Coagmento	1. Navigate to Coagmento Sidebar 2. Navigate to history panel;	Images maps with ambiguous text	The outcome: The evaluator was unable to reach the	The outcome: The evaluator was able view the	Sidebar not accessible	BW, WCAG 1.0, WCAG 2.0 Image maps with no

		click enter 3. Chose a tab “snippets” , “search”, “bookmark” , or “file”; and click enter 4. View the choose history tab by going through the records in the table	description. The images maps represent four arrows to allow the user to scroll upwards and downwards	records.	records but have spent 7 minutes to go through the images in order to reach the actual records.		text
D:6		1. Navigate to Coagmento Sidebar 2. Navigate to notification panel; click enter 3. You can view the notification by going through the records in the table	Dynamic changes to the not rendered by all three screen readers. Outcome: The evaluator was not able view the notification, where the information is not updated instantly.	Outcome: The evaluator was not able view the notification	The keyboard trap Outcome: The evaluator was not able view the notification	Sidebar inaccessible	BW, WCAG 1.0, WCAG 2.0 Dynamic change

D:7	Diigo	1. In the designated group page 2. Navigate to a specified bookmark (doesn't allow to set alerts on topics) 3. Click on "more" drop down menu 4. Chose "enable email notification alert"	"More" drop-down menu is mouse-over object Navigating using keyword will not allow the user to select the mouse-over drop down menu Outcome: the evaluator was unable to access the menu	Common barrier JAWS keyboard command to select mouse-over object don't work.	Common Barrier	Common Barrier	BW, WCAG 1.0, WCAG 2.0 Mouse-over object

Appendix D. Materials for Study 2

This appendix contains materials from study 2 in which we observed VI and sighted users perform a collaborative web search task using ACSZ interface. The appendix consists of a list of the user interaction measures considered, the materials used in the training prior to the sessions, the collaborative search tasks, the post-study satisfaction questionnaire, and the questions used in the semi-structured interview carried out after each session.

D.1 User Interaction Measures

1. Number of words in initial query term (length of initial query term)
2. Number of search results viewed
3. Number of query reformulation
4. Number of times a user has accessed the search component
5. Number of times a user has accessed the folder component
6. Number of times a user has viewed the Stream
7. Number of times a user has accessed team chat
8. Number of times a user has access the Recent activity region
9. Number of teams a user has added stream comment
10. Number of times a user has added post
11. Number of times a user has added link
12. Number of times a user has added file
13. Number of times a user has created folder
14. Number of times a user has edited folder
15. Number of times a user has deleted folder
16. Number of times a user has added comment
17. Number of times a user has deleted comment
18. Number of times a user has deleted saved link
19. Number of times a user has added tag
20. Number of times a user has saved a link
21. Number of times a user has deleted post
22. Number of times a user has edited a post
23. Number of times a user has dragged and Dropped post
24. Number of times a user has moved a post
25. Number of times a user has used past searches
26. Number of times a user has Liked a post
27. Number of times a user has checked a post in folder created by team members
28. Number of times a VI user clicked ALT+CTRL+V to hear Chat messages
29. Number of times a VI user used PlaceMarkers to reach as specific component

D.2 Training Document for VI Participants

Training will include

1. Introduction of the purpose of the system
2. The main components
3. How to reach each component (Search, folders, chat, recent activity)
4. How to create a folder
5. How to use the search
6. How to save a search result to a folder.
7. How to add/delete a post in a folder
8. How to post a chat message
9. How to reach the recent activity
10. How to know you have received an new message
11. How to know you have received an new post

The training will not include the setting required (i.e. installing the script, the place markers or speech and sound scheme)

The Training will roughly be up to 35 minutes. For each task there will be an explanation and a walkthrough. Then the participant will be asked to rate this task in term of how easy it was.

Below are the components of the training:

1. Introduction of the purpose of the system

This will probably take about to 2 minutes which will include a high level description of the system.

2. The main components

Search

Folders

Team chat

Recent activity

3. **How to reach each component (Search, folders, chat, recent activity)**

The four main components are: The Search engine, the Users created folders, the Team Chat and the recent activity Panel.

JAWS Command: CTRL+Shift+ K to reach the placemarkers

Duration of training: 2 Minutes

4. **How to create a folder**

You will be able to create folders and work with teammates to effectively organize the data that you will collect from your searches.

To create a folder, follow the below instruction:

1. Using the Placemarkers move to the folders area. This is done by Pressing CTRL+Shift+ K and then cursor down once. When you hear the word ‘folder, press enter.
2. Using the cursor down keep moving down until you hear ‘create new folder’, press enter.
3. When you hear ‘new folder dialogue’, enter the new folder name.
4. Then choose the save button.

Rate, how easy to create a new folder? (1 being very easy and 10 being extremely hard)

Duration of training: 3 Minutes

5. **How to use the search engine**

Follow the below instruction:

1. Using the Placemarkers move to the folders area. This is done by Pressing CTRL+Shift+ K and then cursor down once. When you hear the word ‘folder, press enter.

2. Press enter on the Search link. That is to take you to the Search Page.
3. In the Search page, Press the ‘Tab’ until you reach the first edit box which will be the search edit field. (Where the voice would change to a female voice). You can now type in your query.
4. Click on the Submit box (where the voice of the screen reader will change to a low pitch voice).

Quick Tip: You can navigate through Search result using (H) key to jump from one search result to another and (H+Shift) to jump backwards.

Rate, how easy use to the search engine? (1 being very easy and 10 being extremely hard)

Duration of training: 3 Minutes

6. How to Save Search Result

Follow the below instruction:

1. You can navigate to the search results by pressing ‘H’ which will allow you to move from one search result to another.
2. To save a search result, on the search result Cursor down until you hear the word ‘save’. Press enter.
3. Then click on cursor up until you hear ‘pick a folder to save’. Using the cursor down find the folder that you want to save the link in and press enter.

Rate, how easy to save a search result? (1 being very easy and 10 being extremely hard)

Duration of training: 3 Minutes

7. How to add/delete a post in a folder

Follow the below instruction:

1. Navigate to the designated folder
2. Cursor down until you listen to ‘add post’, press enter.

3. When you listen to ‘Edit post dialogue’, using the cursor down until you reach the first edit box which is the post title and second edit box which the body of the post.

4. When you entered the title and the post, You can then click on ‘Save’ button. The ‘save’ button is immediately after the post body edit box.

Rate, how easy to add a new post? (1 being very easy and 10 being extremely hard)

Duration of training: 7 Minutes

8. How to post a chat message

Follow the below instruction:

1. Use the PlaceMarkers to bring up the list of components. Cursor down twice; when you listen to ‘Team chat Button Revised document’ press on ‘Move on’ or press enter.

2. When you listen to ‘Team Chat Button Revised’, press enter. That will open the chat window.

3. Then using jaws search (CTRL+F), search for the term ‘team chat’. That will take you to the ‘team chat’ which is just been opened.

4. The edit the box to enter your chat message is underneath the chat dialogue. That chat dialogue has all the chat messages between you and your partner. Most recent message comes in the end. Following that you will find an edit box to enter your chat message.

Note: When you try to access the chat messages for the first time the focus usually lands on the oldest message. However if you try to access it again using place markers the focus usually lands on the send button and you will hear (Graphic send). You will need to cursor back to go back one step to the edit box in which you can type your chat message.

Tip: Quick way to reach a new message: press ALT+Control+V which will bring them all into the JAWS Virtual Viewer for easier inspection as it saves going through the webpage to find the messages.

Rate, how easy to post a new chat message? (1 being very easy and 10 being extremely hard)

Duration of training: 7 Minutes

9. How to check the recent activity

Follow the below instruction:

1. Use the PlaceMarkers to bring up the list of components. Cursor down three times; when you listen to the phrase ‘recent activity’. Press enter.
2. You can navigate through this panel using the arrow keys.

Tip: Reaching the recent activity panel might sometimes not work using PlaceMarkers due to the html code changing constantly to facilitate page update. Another way of reaching recent activity panel is by Using JAWS find functionality. By clicking on CTRL +F you type in recent activity and then press enter to reach the panel, which saves going through the webpage.

Duration of training: 2 Minutes

Rate, how easy to reach the recent activity panel? (1 being very easy and 10 being extremely hard)

10. How to know you have received an new post

The demonstrator will be giving you a live example and will allow you to navigate to the given folder

To repeat the notification message press F12

Rate, was the notification message clear enough (1 very clear and 10 not clear at all)

Duration of training: 4 Minutes

11. How to know you have received an new chat message

The demonstrator will be giving you a live example and will allow you to navigate to chat messages.

To reach the new message, press ALT+Control+V which open the JAWS Virtual Viewer which will have all the chat messages. This will save you going through the webpage.

Rate, was the notification message clear enough (1 very clear and 10 not clear at all)

Duration of training: 4 Minutes

D.3 Training Document for Sighted Participants

Training will include

1. Introduction of the purpose of the system
2. The main components
3. How to create a folder
4. How to use the search
5. How to save a search result to a folder.
6. How to add/delete a post in a folder
7. How to post a chat message
8. How to check the recent activity
9. How to know you have received a new post
10. How to know you have received a new message

Training should take from 15 to 20 minutes.

Below are the components of the training:

1. Introduction of the purpose of the system

ACS Zakta is a collaborative search engine that allows collaborators to search the web together, share websites, and comment on shared websites. It also allows collaborators to chat together.

2. The main components as shown in figure 1

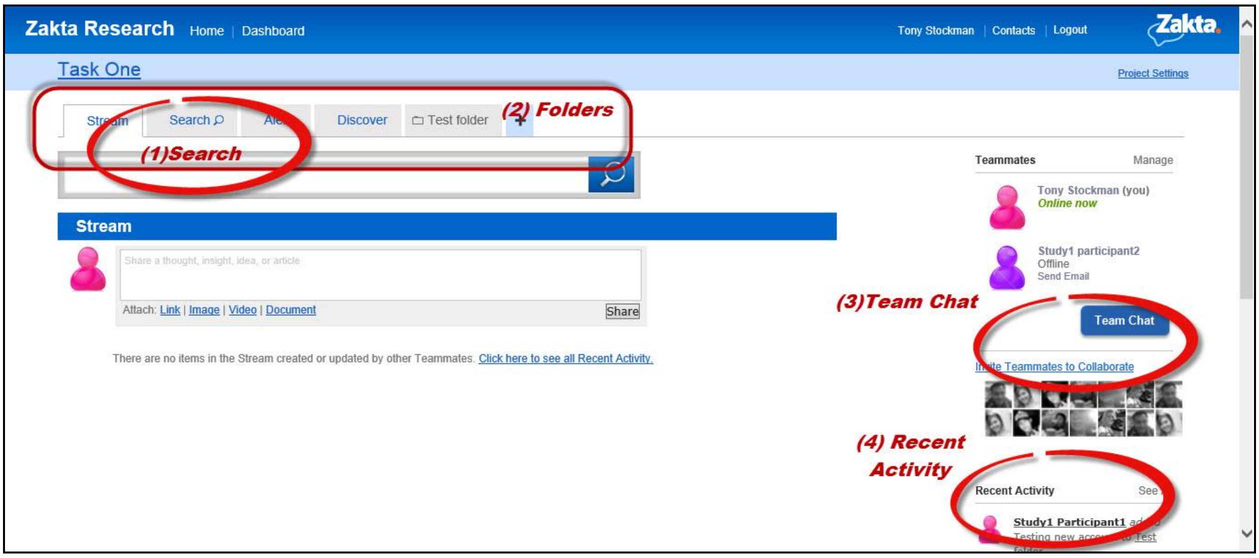

Figure 1. ACSZ system: (1) Search engine tab. (2) Create New Folder Tab. (3) Team Chat button to open Team Chat modal dialogue form (4) Recent Activity Region.

3. How to create a folder

You will be able to create folders and work with teammates to effectively organize the data that you will collect from your searches.

To create a folder, follow the below instruction:

1. This done by clicking on the create folder button, which is the add (+) next to the last folder as shown in figure 2.

2. Clicking on it will launch a dialogue box that will allow you to specifying a name for the folder.

Figure 2. Create folder button

Rate, how easy to create a new folder? (1 being very easy and 10 being extremely hard)

Duration of training: 2 Minutes

4. How to use the search engine

To use search engine:

1. In the folder area, click on Search (as shown in figure 1).

2. A search engine with text box to enter your search query will appear. You can then enter your search query terms.

Next to the Search button there is a past searches box in which you can view past queries which all collaborators (including yourself) have entered. You will be able to view the last four queries entered.

Rate, how easy use to the search engine? (1 being very easy and 10 being extremely hard)

Duration of training: 3 Minutes

5. How to Save Search Result

Next to each Search result there are Save and Hide buttons. These allow you to save the search results in one of the folders that you or your partner have created or to hide some search results so that you can more effectively sort through the unhidden results.

To save search results:

1. Chose a search result, and press the save button next to it.
2. A dialogue box will appear, chose the folder you would like to save the search result in.

Rate, how easy to save a search result? (1 being very easy and 10 being extremely hard)

Duration of training: 2 Minutes

6. How to add/delete a post in a folder

Once in a folder, you can manually add/delete a link, add a post in which you can simply type information which will get posted to the folder, or you can add a file straight from your computer.

To add a post to a folder:

1. Navigate to the folder that you want to add a post in.
2. Click on the folder, then press on add a new post.
3. A Form with two text boxes will appear. The first text box is for the title of the post and the second text box is for the body of the post. After filling both text boxes, you need to click on the save button to save your post. Remember you can also add a link or a file to a folder following broadly similar steps.

Rate, how easy to add a new post? (1 being very easy and 10 being extremely hard)

Duration of training: 3 Minutes

7. How to post a chat message

To send a new chat message.

3. Click on Team chat button shown in Figure1.
4. The chat dialogue box will appear as shown in figure 4.
5. Enter your chat message and click the send button.

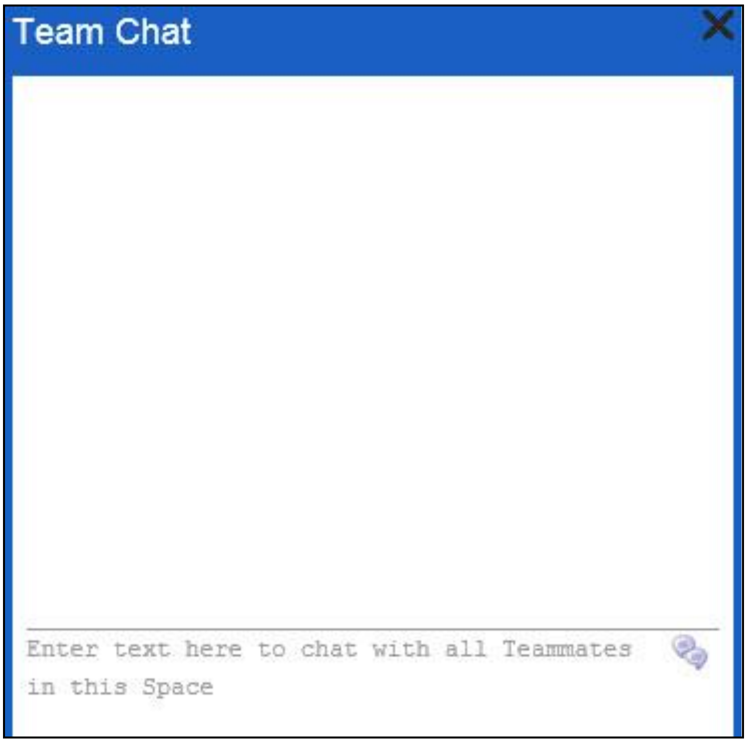

Figure 4. Team Chat dialogue box

Rate, how easy to post a new chat message? (1 being very easy and 10 being extremely hard)

Duration of training: 3 Minutes

8. How to check the recent activity

You can simply navigate through this panel. It contains all the recent updates by your teammates. Every time anybody in the Project comments on something, moves something, adds something, updates something, or makes any sort of change in the Project at all, the Recent Activity feed notifies you.

Rate, how easy to reach the recent activity panel? (1 being very easy and 10 being extremely hard)

Duration of training: 2 Minutes

9. **How to know you have received an new post**

Every time a new post is added a number next to the folder name will appear as shown in Figure 3. The number next to the user created folder indicates the total number of new posts (which may also include comments on posts).

Figure 3. New post in user created folders

Note: This action can only be seen if a new post was posted by another collaborators/teammate.

10. How to know you have received an new chat message

The chat message will appear in the chat dialogue box.

D.4 Collaborative Search Tasks

Co-Located Setting Task

This year the software engineering company you work for is launching a new customer relations system that handles customers' and products' information and all payments and transactions. You and three of your teammates are in charge of a marketing campaign in the Middle East. The campaign will take place in three cities, which are Beirut in Lebanon, Manama in Bahrain and Dubai in UAE. You are required to book flights and accommodation for three cities as well as activities in each city which are detailed below.

You will be arriving Beirut Monday the 11th of august for three days. The first two days you will be participating in annual fair located in the "forum de beyrouth". On the third day, you need to plan an activity to do in the morning before your afternoon flight to Bahrain. This may be visiting a shopping mall, a historical place or going on a sightseeing tour.

In Bahrain, you will also be participating in an annual fair located in Sharton Hotel- Manama for two days which will be the 15th and 16th of August. On the first day, following the fair, you and your colleagues will need to invite three of your business partners to a dinner in a restaurant in the capital city of Bahrain (Manama). You will need to find a restaurant. On the second day and following the fair which ends at 3pm, you would need to organize an activity to do for the rest of the day. This may include visiting a historical site, going to the beach, or even visiting a shopping mall.

You will be arriving Dubai on the 17th of August. In Dubai you are in charge of arranging a two day workshop to train participants on using the systems. You will have 20 attendees. You will need to book a venue. You will need to make sure that the venue has internet access, a white board and data projector. You will also need to book catering. On the last day which is the 19th you will need to hold an evening reception for all your business partners in the UAE for networking and informal discussion for about 15 attendees.

In the next 35 minutes, organize this trip with your partner. Using ACSZ you can search for the information, share it with your partner and communicate with them.

Please, note you don't need to actually make the booking but you need to take notes of all details that will help you both in making the actual booking later in time.

Distributed Condition

This year the leather goods company you work for is looking for new partners in Italy. You and three of your teammates are in charge of meeting with possible partners in Italy. You will go on a trip to Italy this august which will include three cities: Rome, Florence and Venice. You are required to book flights and accommodation for three cities as well as activities in each city which are detailed below.

You will be arriving Rome Monday the 11th of August for two days. On the first day you will need to book a restaurant for a business dinner for five (including your team). The following day you will need to organize an activity to do. It might be attending a play, visiting a historical site, or any sort of activity. You will be reaching Florence on the 13th of August, on the next day you will need to book a restaurant for a business launch for four (including your team).

You will be arriving to Venice on the 15th of August. In Venice you are in charge of arranging a day workshop for your possible business partners about the company’s strategy, products and roadmap, which will take place on the 16th of August. You will need to book a venue for 20 attendees. You will need to make sure that the venue has internet access, a white board and data projector. You will also need to book catering. On the following day, you will need to hold an evening reception for your business partners in Venice for networking and informal discussion for about 15 attendees.

In the next 35 minutes, organize this trip with your partner. Using ACSZ you can search for the information, share it with your partner and communicate with them.

Please, note you don’t need to actually make the booking but you need to take notes of all details that will help you both in making the actual booking later in time.

D.5 Post-study Questionnaire

Please rate the following statements (10 being the most satisfactory and 1 being the least satisfactory). If you have not used the feature please state so.

Please note that statements that start with (*) symbol are not required to be answered by the sighted participants.

General

1. The Usability of the tool
2. (*) The Accessibility of the tool
3. The ability to search the web collaboratively using this tool
4. The usefulness of being able to create folders
5. The usefulness of team chat functionality

Result management and sharing

6. How confident are you about creating a folder
7. How confident are you about adding a post in a folder.
8. How confident are you about sending a message using the team chat feature
9. How confident are you about adding a comment to a post
10. How confident are you about viewing new post and comments in a folder

Individual Information Seeking

1. The usability of the search engine
2. The usefulness of The ‘Save’ Button next to Search Result
3. The usability of the ‘hide’ button
4. The usefulness of having a search engine integrated to the website.

Awareness

5. (*) The usefulness of the sound alerts
6. The usefulness of Recent activity panel

7. The usefulness of having an update of your partner activity

8. The usefulness of knowing the search keywords your partner have used

9. The ability to know that a new post has been added to a folder

10. The ability to know that a new chat message has been received.

JAWS Screen Reader Script

11. (*)The usefulness of Plackmarkers in helping you reaching the main components of the page

12. (*)The usefulness of the change in JAWS voice in helping you different buttons and edit boxes

13. (*)The usefulness of JAWS Script Short cuts F12 for repeating folder update message

14. (*)The usefulness of JAWS Script Short cuts ALT+Control+V for viewing chat messages.

Team

15. You and your partner overall performance of the whole task

16. You and your partner communication level

17. The distribution of task between you and your partner.

18. You and your partner decision making process

D.6 Post-study Interview Questions

1. The most useful feature(s) (if you have more than one feature in mind, please order them in terms of their usefulness) (give example)

2. The least useful Feature(s)

3. (*) Inaccessible Feature(s)

4. How often did you check the recent activity

5. Having the chance to user ACSZ during the experiment, is there any feature you would like to add to this tool? If yes, please Specify.

6. Compared to the previous study that you have participated in, did you find this process easier or harder and why?