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Evaluating an Interface for Cross-modal Collaborative Information Seeking

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The objective of the work reported here is to develop an understanding of cross-modal collaborative information-seeking (CCIS) between visually impaired (VI) and sighted users in order to learn how best to support it. In a previous article, we reported the CCIS process that occurred when 14 pairs of users, one sighted and one VI, performed web-based collaborative information seeking tasks in two settings: co-located and distributed. In that study, participants used their tools of choice: web browsers, search engines, notetakers and communication tools. We discussed the difficulties encountered, including those imposed on VI users due to the current limitations of screen readers.

In this article, we report a study using the same participants undertaking similar search tasks, but this time using a commercially available collaborative information seeking (CIS) system, which we enhanced to improve its accessibility. In this study, in order to examine the impact of the interface on the process, we looked at the CCIS process from two perspectives: the actions of individuals collaborating with one another and the interactions of each individual with each interface. The results showed that both sighted and VI users benefited from the use of an integrated, purpose-built tool, both in terms of task performance and levels of satisfaction. The analysis of these interactions is then used to formulate guidelines for the design of accessible CCIS systems.

RESEARCH HIGHLIGHTS

- Evaluating a cross-modal collaborative search interface with blind and sighted users
- Investigating workspace and group awareness in a cross-modal context
- An integrated interface improved the visually impaired and sighted users' interaction and performance
- Guidelines for designing systems that support inclusive collaboration.

Keywords: collaborative search, cross-modal interaction, usability evaluation, empirical studies in accessibility, observational studies

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1. INTRODUCTION

In educational and work settings, people frequently collaborate when searching for information, even if they are not explicitly asked to work together (Large et al., 2002; Morris, 2008). This is often described as a group of people searching with a shared information need. This can occur in a variety of settings either in educational environments (Foster, 2009), professional workplaces (Morris, 2008) or these days on social media platforms (Hecht et al., 2012). Recent research in collaborative information seeking (CIS) has aimed at providing solutions and frameworks to support this process (Golovchinsky et al., 2009; Morris et al., 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) students or employees in educational settings or workplaces may often have to collaborate with sighted team members when searching the web. We refer to this type of interaction as cross-modal collaborative information seeking (CCIS). Individual VI search behaviour is challenged by substantial issues imposed by the current state of assistive technology (Stockman and Metatla, 2008; Sahib et al., 2012). Thus, engaging in web search activities with peers can be a major barrier to workplace collaboration and can impose a number of challenges on efficient collaborative work. Some of these challenges are documented in our previous work, (Al-Thani et al., 2013), in which we carried out an exploratory observational study with VI and sighted users performing a collaborative web search task. The work is briefly discussed later in section 2.2 of this article.

In the present article, we describe an evaluation study that explores CCIS behaviour between VI and sighted participants using a tool that goes some way directly to support it, i.e. a tool that provides a relatively accessible shared workspace and group and workspace awareness mechanisms. We refer to the status of the information seeking task as group awareness and the status of the shared workspace as workspace awareness (Gross, 2013). The overall aim is to understand the behaviour, process and challenges that arise when a mainstream CIS tool, adapted to improve its accessibility, is employed to support CCIS. The rest of this article is structured as follows: section 2.1 surveys the literature on different approaches to evaluating collaborative information seeking. Section 2.2 provides a brief description of our previous study, necessary to understand the comparisons made with the present study in later sections of this paper. The features and accessibility enhancements made to the CIS tool used in the evaluation are outlined in section 3. The evaluation methodology and research questions are then discussed in detail in section 4. Section 5 describes the study design, which is followed by a description of the main findings of the study in section 6. Section 7 builds on these findings by synthesising a set of guidelines toward the inclusive design of CIS systems.

2. RELATED WORK

In this section, we give an overview of work done in the field of CIS, before going on to present different approaches to CIS system evaluation, by looking at how CIS is examined in empirical studies. In this article, many references are made to our previous study, which is used as a base-line for comparison for the part of the present study focusing on the collaborative interaction. Thus, in section 2.2, we briefly summarize the previous study by discussing its methodology and main findings.

For years, web search engines were always built with individual users in mind. This was despite the fact that numerous studies in educational settings and workplaces indicated that people often chose to work together in groups on a search task, even if they were not asked explicitly to do so (Allen, 1977; Twidale et al., 1997; Large et al., 2002). It was not until the last decade that 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, individually-centred information seeking would not be sufficient (Foster, 2006).

The social dimension or the human-human interaction component was now recognized as a key part of the process. Various terms in the field of IR and HCI have been used to refer to this area of research. These terms include: 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 terms, 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).

2.1 CIS evaluation

Given the complexity of the context and the multi-dimensional nature of the issues involved in the CIS process, evaluation of the process can be challenging. CSCW literature has long considered evaluation one of the major challenges (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. Along 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) refers to these dimensions as system-focused, user-focused and collaboration-focused. He encouraged researchers to look at the CIS activity in more than one dimension in order to understand fully the process and the context through which it was being examined.

Studies that are system-focused have their roots in the domain of Information Retrieval (IR). 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 often employ simulation-based experiments to evaluate system performance.

Examining the CIS literature, it is clear that the majority of the empirical studies in this field are user-focused. In these studies, the quality of the interface is measured using instruments taken from the HCI and cognitive science literatures. 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. For example, to collect initial requirements for designing a CIS interface, Morris (2008) conducted a survey, while Shah and Marchionini (2010) undertook a series of interviews.

Collaboration-focused studies investigate the different aspects of collaboration such as division of labour, awareness and cognitive load, with qualitative data analysis as an important tool in the process. An example of this is the paper by Foster (2010), who developed a coding guide for analysing peers' conversations 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 developed was informed by the "sequential organization of spoken discourse" analytical framework, a language-based theory of learning developed by Wells (1999). 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 data 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, 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-recordings as well as group chat logs. The outcome highlighted the challenges that ad hoc tools impose on collaborative sense-making and suggests design implications to aid the process.

2.2 Previous exploratory observation study

As part of our previous study, reported in (Al-Thani et al., 2013), we examined the interactions that occur between sighted and VI users when collaboratively searching the web. In this previous study, users employed the usual tools that they used for performing such searches: their preferred browser, search engine, email client and in the case of VI users, their preferred screen reader. We analysed users' conversations and interactions with applications in co-located and distributed settings, using a combination of qualitative and quantitative analyses. 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. Our findings showed the influence of the different interaction modalities employed, as well as differences due to whether pairs were working together co-located or distributed from one another. The effects of these factors were most clearly seen in the way pairs opted to divide the labour involved in search tasks, and the way in which they provided and used awareness information. Asymmetric division of labour strategies were employed to try to overcome the challenges imposed by accessibility issues and the use of different interaction modalities. The study also helped in identifying the distinct stages of information seeking that were performed collaboratively and the incidents that triggered the collaboration. The findings showed that the different stages of the process were performed individually most of the time. However, it was observed that some collaboration took place in the results exploration and management stages. The web accessibility challenges faced by VI users affected their individual and collaborative interactions and also enforced certain points of collaboration.

Our study highlighted a number of issues faced by the pairs of users taking part in CCIS: some of these issues had an underlying individual web accessibility issue, while some arose from the collaborative nature of the activity. In terms of web accessibility for individual VI participants, primarily two issues occurred:

1. The problem of scanning large sets of results using speech-based screen readers. On many occasions VI users were observed seeking the help of their sighted partners in the session to view large volumes of search results. This problem arises in part through the lack of effective and accessible overview mechanisms in current search engines and/or screen-readers (Stockman and Metatla, 2008).
2. The fact that individual web components, for example parts of web forms, had limited or no accessibility for VI users also affected their choices in performing tasks and in dividing the labour between themselves and their sighted partners.

Issues that arose from their collaborative work included the effort that was required in providing awareness information to each other and the lack of accessible, consolidated tools that support CCIS, including the lack of a shared workspace and group and workspace awareness mechanisms. The challenges and behaviour patterns identified in this exploratory study gave rise to a set of design recommendations to improve the accessibility of the CCIS process (Al-Thani et al., 2016).

3. THE CIS INTERFACE

At the time study 2 was carried out, there were only three CIS interfaces available online: Coagmento[1], Diigo[2], and SearchTeam. Coagmento was developed by Shah and Marchionini (2010) as a part of Shah's PhD work. It was a standalone system, which was subsequently redesigned as a Firefox and Google Chrome browser plugin to support distributed CIS. SearchTeam and Diigo are commercially available web applications. Diigo is a web tool that allows personal and collaborative bookmarking and SearchTeam, a product of Zakta[3], is a real-time collaborative search engine, which was specifically developed to help users when performing CIS tasks on the web.

We performed an accessibility evaluation on all three interfaces in order to determine the most eligible CIS system that had sufficient levels of accessibility and which provided both workplace and group awareness mechanisms to support the CIS process. To assess the accessibility of the three systems, 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 Content Accessibility Guidelines (WCAG 2.0) (Caldwell et al., 2006). It helped us in identifying both accessibility and usability issues in the interface that we would try to resolve prior to performing the study with participants. There were substantial differences in levels of accessibility and barriers recorded across the different interfaces. Coagmento and Diigo have major accessibility issues when navigating to essential features in the toolbar which would likely hinder VI users from performing many key CIS tasks. Within SearchTeam, most functionality was fairly accessible: the tasks were conducted relatively easily. Minor issues were encountered when accessing parts of a web form within the system. That is in addition to the lack of alternative text in some edit fields. The details of the accessibility review can be found in (Al-Thani, 2016, pp. 182-186).

3.1. CIS Interface features

Within SearchTeam (Figure 1), each collaborative search task is conducted within what is called a SearchSpace. Within a SearchSpace, collaborators search the web together and save and edit their results. 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 have left off. Results are organized into user-created folders within the SearchSpace. Within these folders, collaborators can comment on search results, "like" them, "add post"s, 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.

3.2. Enhancements made to the CIS interface

In this study, all VI users accessed the SearchTeam interface using the JAWS[4] screen reader with synthetic speech output. JAWS is the most widely used screen reader worldwide (WebAIM, 2015). It supports scripting and other mechanisms to improve access to specific applications. To enhance the experience of VI users, we introduced two types of enhancements respectively to support awareness of dynamic changes and navigation. Table 1 details the enhancements made.

Feature name	Feature type	Description
	To support awareness	
New post alert	Audio message	that reads the names of the folders that have been updated
New chat message alert	Audio message	Audio message notifying a VI user of the arrival of a new chat message
	To support navigation	
PlaceMarker	JAWS screen-reader setting	JAWS screen-reader feature to help VI users navigate quickly to the major components of the ACSZ interface.
Audible chat messages	Keyboard shortcut (Hot key)	Users can view the chat dialogue without having to navigate to team chat

Table 1. Enhancements made to SearchTeam.

The option of improving its accessibility by modifying the underlying source code was not available as we had no access to the source code of the application used, therefore, using JAWS scripts and settings was the way forward. We developed a JAWS script that notifies the users of dynamic data changes and assists them in navigating the interface. The JAWS script employs sound alerts to notify users when a "new post" is added to a folder or a "new chat message" arrives. To support more efficient navigation by VI users of the SearchTeam interface, we introduced JAWS PlaceMarkers, which enable fast navigation to commonly accessed areas within an HTML document. Additionally, we

[1] http://www.coagmento.org/

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

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

[4] www.freedomscientific.com

provided a JAWS script that allowed VI users to view the chat dialogue without having to navigate to the team chat modal dialogue form. We named the extended SearchTeam interface Accessible Collaborative Searching Zakta (ACSZ).

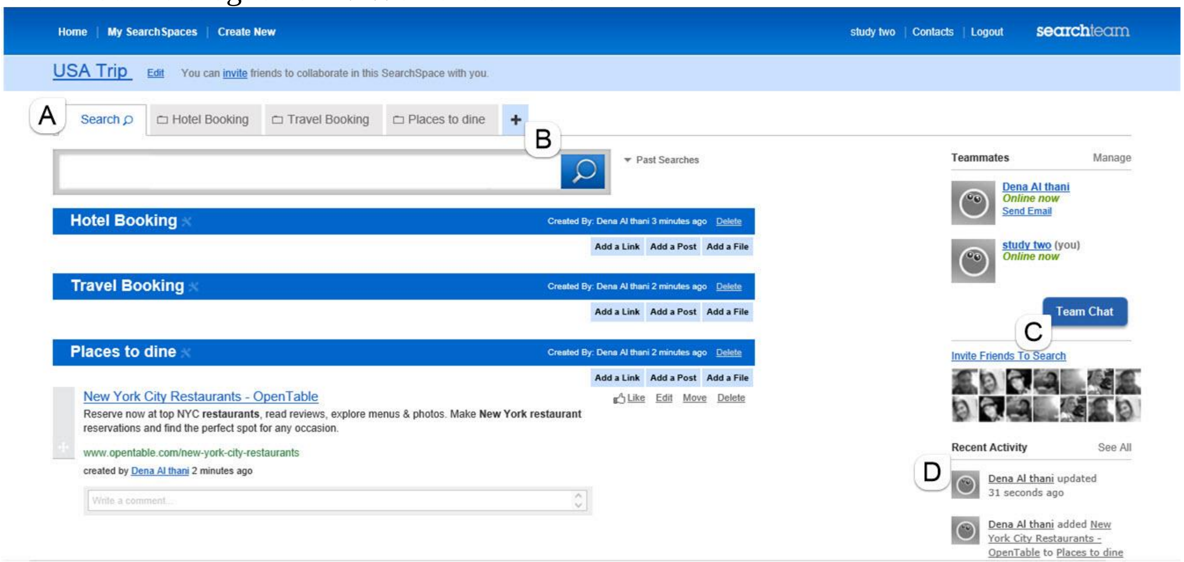

Figure 1. The SearchTeam interface: (A) search engine tab. (B) create new folder tab. (C) team chat button to open the team chat modal dialogue form (D) recent activity region.

4. EVALUATION METHODOLOGY AND RESEARCH QUESTIONS

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 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. It also explores individual user behaviour in terms of the usability and accessibility issues encountered. To the best of our knowledge, this is the first study that examines the CCIS process using a system tailored specifically to support it.

Given the complexity of the CCIS process, the evaluation is examined from various angles, including the collaboration, the individual users and the system, as Shah (2014) described. Thus, we defined a set of research questions (RQs) based on the two dimensions of CIS evaluation: individual user interactions with the interface and the collaboration between users. In terms of the collaboration, for comparison we use as a baseline the results reported in Al-Thani et al. (2013) and (2016) blinded for per review). We consider those results as providing a baseline since they were obtained with the collaborating users not employing any system specifically designed to support CCIS (no such system being in existence, to the best of our knowledge), but simply using the browser, word processing and messaging tools of their choice to perform the collaborative search. Direct comparisons are made in this paper wherever possible between those baseline results and the results of the present study, which were obtained using the SearchTeam system enhanced for accessibility. We refer to the baseline results as study 1 in the rest of this article, and to the results of the present study as study 2. 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 supports CCIS.

4.1. The collaborative dimension

This section focuses on the collaborators' joint performance and their interactions to facilitate awareness. Measures of CIS performance are likely to vary depending on both the aims of the searchers and, to some degree, with the platform they are using. In this research, we based the task performance evaluation on the number of tasks completed and the number of tasks that overlapped.

> **RQ 1:** Is the number of subtasks completed greater when using the ACSZ system than the number of subtasks completed when using separate applications (study 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. In study 1, the tasks consisted of planning a trip to three different cities with activities to be organized in each city. In study 2, the modifications included 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. Hence, the tasks used in this study are equal in structure and in the amount of information to be retrieved and synthesised to those used in study 1.

In the co-located condition in study 2, 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 involved visiting three cities; the participants were 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 to make the actual booking later in time.

We observed the number of tasks completed by each pair and by each collaborator, the number of tasks performed collaboratively and the number of tasks that overlapped. Task overlap refers to the situation where one subtask is mistakenly done by both collaborators. RQ1 compares the results of this study to the results of study 1 to identify the impact of the ACSZ interface on participants' task completion.

> **RQ 2:** 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 a shared workspace as well as a number of features that provide group and workspace awareness information. It is important to note here that we refer to the awareness of group members' activities at a given time as group awareness and the awareness of activities between collaborators as workspace awareness. 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 partners in an attempt to improve group awareness. RQ2 investigates whether the group and workspace awareness information available using the ACSZ interface had an impact on the amount and type of awareness information explicitly exchanged between partners.

4.2. The user interaction dimension

This section focuses on the individual information seeking (IS) process, individual user interactions with the interface, and specifically on VI participants' interactions with accessibility enhancements made to the interface.

> **RQ 3:** What are the effects of the use of ACSZ on information seeking behaviour?
> **RQ 4:** How do the participants organize and manage retrieved search results in the presence of a shared workspace?

Studies have revealed that IS stages are typically completed individually most of the time, with occasional instances of collaboration (Shah and Marchionini, 2010; Shah and González-Ibáñez, 2010). In study 1 (Al-Thani, et al., 2016), it was seen that the stages of IS were performed individually most of the time. In RQ3 we look into the stages of IS when using the ACSZ tool. We explore the amount of collaboration that happens at each stage and the effect of the tool on the stages of IS.

> **RQ5:** Are the participants satisfied with the overall user experience? And
> **RQ6:** How do VI users interact with the awareness and navigation enhancements made?

RQ5 investigates specific features of the tool that are used, and whether these appear to improve the usability of the system and/or improve the performance of tasks. We identify features that are not used or that cause confusion or reduce usability. RQ6 looks into the frequency of use of the main accessibility enhancements, including the JAWS scripted features and PlaceMarkers, the accessibility issues encountered and the ease of use and satisfaction levels.

5. STUDY DESIGN

5.1. Participants

For this study the same 14 sighted and VI pairs that participated in study 1 were recruited. They were contacted by email. The fact that they also took part in study 1 seems unlikely to have had any significant effect on their performance in study 2, for two reasons. Firstly, it was quite a long period of time, about 15 months, between study 1 and study 2. Secondly, in study 2, the participants had to use a new interface that was substantially different from those used in study 1. Table 2 details participants' demographic data. When VI participants were asked about their use of assistive technology they all said that JAWS was their primary screen reader. Two pairs had been colleagues for more than two years. None of the other pairs had worked together on a regular basis.

	Visually Impaired 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	8 Male, 6 Female	8 Male, 6 Female
Browser Used (Multiple Answers)	12 IE, 8 Safari, 5 Firefox	6 IE, 4 Firefox 3 Safari, 1 Chrome
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

Table 2. Demographic information of the participants.

5.2. Procedure

Each session included three main parts. We first asked the participants to answer a pre-study questionnaire which gathered information about the type of assistive technology they use, their familiarity with search engines and how long they had been working together. This was followed by a brief training tutorial where we introduced them to the main components of the interface. We also presented to the participants the tasks they would perform.

Participants were then provided with a 10-minute 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 training, the pairs were asked to start performing a CIS task, using the CIS interface. We counterbalanced the order of the tasks across the pairs to minimize the influence that task order might have on the collected data. In each task, the users were stopped after 35 minutes. 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. The final part of the study was the post-study questionnaire and interview. In this interview, we asked participants to rate their satisfaction regarding the usability and accessibility of the interface, and discuss issues and challenges encountered

5.3. Data 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. We employed an inductive content analysis approach, similar to Grounded Theory (Strauss and Corbin, 1990). We identified concepts from the recordings and formulated a coding scheme to highlight common issues across different participants. One view of 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 between search interfaces, between search tasks and 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. This study is similar to Makri et al.(2008) and Sahib et al.(2012), in that we seek to understand the CCIS behaviour between VI and sighted users and not to develop a new theory. Thus, the selective coding stage was not conducted and the analysis was terminated after open and axial coding. The data coding scheme can be found in appendix A. The transcribed screen recordings provided qualitative data and screen logs were used to derive quantitative data such as the use of features, the web accessibility issues encountered, the websites explored and the number of query terms entered.

The study concluded with a post-study satisfaction questionnaire to measure the ease of use of the system. 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 its use. Responses to these questions provided information on the perceived ease of use and the levels of satisfaction with the tasks. This was followed by a brief semi-structured interview that was conducted individually with each participant to complement the data collected during the study.

6. DISCUSSION OF FINDINGS

In this section we synthesis the main findings of this study, based on the two main perspectives identified in the research questions (section 4): the collaborative and the individual interactions with the interface. This section starts with a discussion related to the collaboration in section 6.1. The discussion considers study 1, reported in Al-Thani et al. (2013) and (2016), as the baseline study. It discusses the results in light of study 1, making direct comparisons where possible. The individual interactions perspective, discussed in section 6.2, comprises the individual IS behaviour, the user interactions and the related usability issues. In terms of the individual IS, and similar to the collaborative aspect, we consider the results of study 1 as our baseline study, with 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.

6.1. The collaboration

6.1.1. *Users' task performance*

RQ1: Is the number of sub-tasks completed greater when using ACSZ (study 2) than when using software tools which users routinely employ in everyday tasks (study 1)?

Calculating how far a pair reached in a given task can be one indicator of task performance. To answer this question, we looked at differences in task completion between the two conditions of study 2 and compared the results with those of study 1. In each condition, the pair was asked to collaboratively perform a task of organizing a business trip as described in 4.1. The task consisted of 13 subtasks that the pair had to complete.

In study 2, two pairs from each condition completed the overall task within the allocated 35 minutes. The same two pairs completed the overall tasks in both the co-located and distributed settings. The average number of subtasks completed in the co-located condition was (10.14 subtasks, SD=1.8) and the average number of subtasks completed in the distributed condition was (9.42 subtasks, SD=1.83). The differences between the two conditions is not significant with t-test results at ($t(26) = 2.05$, $p=0.722$). In study 1, the sighted participants performed a slightly higher number of subtasks than 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 subtasks completed by both VI and sighted participants was slightly higher than the average number of subtasks completed in study 1 in both conditions. However, the difference 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 subtasks in both conditions of study 2, there were instances where both participants performed the same subtasks. 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. There was a slight improvement in the second study, where the average number of occurrences was slightly smaller. The number of subtasks completed together was slightly higher in study 1. Two factors were highlighted in study 1 as the reason behind completing a subtask together (Al-Thani et al., 2013). 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 is 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 subtask together in the distributed setting and only one occurrence in the co-located setting.

Finding 1- The interface helped the participants to complete the tasks more efficiently. The shared workspace helped participants in collaboratively making sense of the data. Thus, it was only rarely observed that the participants would explicitly collaborate to complete a subtask.

6.1.2. *Awareness*

RQ2: 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. These features provide both workspace and group awareness. When comparing the results of study 2 with the results from study 1, it is clear that the existence of the shared workspace and awareness features affected both the volume and type of information explicitly exchanged by collaborators.

Participants exchanged information either verbally in the co-located condition or in written form in the distributed condition. The information exchanged would be related to group or workspace awareness, while on less common occasions there would be some discussion of an issue related to the search task. Discussions between collaborating partners concerned supplied or requested information; they regularly notified each other about new information they added or about a post they commented on in the shared workspace. Examples of instances of information exchanged between participants are presented below, which are extracts of conversations in the co-located condition:

> VI participant: *"Historical site in Bahrain, you look for that I will look for restaurants"* (Category: Supplied related to group awareness)
>
> Sighted participant: *"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)

In terms of the volume of information exchanged, there are clear differences between study 1 and study 2. Previous research highlighted a strong correlation between the availability of awareness information and the volume of information exchanged and the time spent making these exchanges (Shah, 2013). Shah defined "coordination effort" as the number of coordination messages exchanged throughout the CIS activity and the time spent sending and receiving messages. Table 3 shows the number of instances of when information was supplied and requested in study 2. The highest proportion of information exchanged was related to supplied awareness information, while the proportion of requested information was low in both conditions. The data in table 3 also illustrates that the volume of information supplied and requested relating to group awareness was much higher than that of the information supplied and requested 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]
Requested 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 3. Number of instances of information supplied and requested. (Average [SD]).

When comparing the two studies, it can be inferred that the average amount of information exchanged was 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 the chi-square test giving ($\chi2= 42.22$, $p < 0.0001$) in the co-located setting and ($\chi2= 4.98$, $p=0.02$) in the distributed setting. In study 1, participants would supply or request information to avoid duplicating effort and to find out how their partners were progressing. The awareness-related features in ACSZ made information about collaborators' activities readily available in study 2; therefore, the average amount of supplied and requested information was much lower in study 2.

Moreover, the availability of awareness information affected the time spent in exchanging information in the distributed condition. In study 1, the communication tools, such as email and instant chat messaging clients, were used to communicate awareness information in the distributed condition, while in study 2, ACSZ provided awareness information via its features, including the integrated chat tool (team chat). In study 2 much less time was spent using team chat than was spent using a chat tool in study 1. This difference was more apparent with visually impaired participants' use of the tool. The average time spent using the chat tool by VI participants was (05:31 minutes, SD= 03:45) and the average time spent using the chat tool by sighted participants was (04:27 minutes, SD= 01:30). The difference between the time spent using the communication tools is statistically significant with sighted participants at ($t(25)= 3.16$ and $p=0.004$). On average, VI participants used the communication tool less in study 2; the difference was not significant at ($t(25)=1.45$ and $p=0.16$).

In study 1, the pairs used the communication tools 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 (2013) in which it was shown that as workspace and group awareness information became available in an interface in a distributed condition, participants expended less "coordination effort" in reporting their actions. It is interesting that this finding from CIS research appears to transfer into a cross-modal context. Moreover, in our study, this finding is also present in the co-located condition.

> **Finding 2-** 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.

In terms of the type of information exchanged, it was observed that in study 2, the information supplied or requested by participants concerned either group awareness or workspace awareness. The latter 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 shown in table 3. In fact, the occurrences of requests for information about workspace awareness were minimal in the co-located setting and there were no occurrences at all in the distributed setting. ACSZ provided a lot of information regarding workspace awareness, but very little regarding group awareness (i.e. query terms entered, websites explored, posts and links being added to the folders). It was observed that the participants used these interface features quite often to check their partner's search progress and updates made in the shared workspace, as shown in table 4. This could be why the participants provided more information about their progress to promote group awareness and less information about the organization and management of information to enhance workspace awareness.

		VI participants		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 4. Summary of the number of accesses of the recent activity region and the folders tab.

> **Finding 3-** Awareness information made available by the ACSZ interface had an influence on the type of awareness information supplied or requested by collaborators.
>
> **Finding 4-** The introduction of a tool that supports 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.

6.2 The individual interaction

6.2.1 Stages of IS

RQ 3: 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. Additionally, one incident was 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 had viewed (using the "past search" feature). To answer RQ3, we examine the different stages of IS and then compare the results with study 1.

Query formation: The average length of initial queries entered by VI participants in the co-located condition was (3.06 words, SD=0.56) and the average length of initial queries entered by sighted participants was (2.03 words, SD= 1.00). In the distributed setting, the average length of initial queries entered by VI participants was (2.75 words, SD= 0.59) and the average length of initial queries entered by sighted users in the distributed setting was (2.46 words, SD= 0.59). Participants sometimes suggested query keywords for their 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.

Results exploration: In the co-located condition, the average number of search results viewed by VI participants was (2.92 search results, SD= 2.23) and the average number of search results explored by sighted participants was (4.64 search results, SD=2.52). Three VI participants 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 was (3.28 search results, SD= 3.04) and the average number of search results explored by sighted participants was (5.69 search results, SD= 2.59[5]). Similar to the co-located condition, we observed three VI participants and one sighted participant who did not explore any search results.

The reason these participants decided not to explore any web search results is due to the way the interface is designed. In the interface, 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 interface window and store the required information using the interface features. It was clear that this process affected the IS behaviour of both VI and sighted participants, in that they preferred not to leave the interface and use the "save link" feature without actually accessing the website.

In the post-study interviews, three VI participants mentioned that they found the way ACSZ opens a new window when showing a web result to be quite confusing. Both VI and sighted participants highlighted a design issue which affected their IS activity. 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. Four VI and three sighted participants reported that opening web search results in a new window confused them; one sighted participant stated "*It would be preferable to have the website open in the same page*".

The average number of search results viewed collaboratively was (0.28 search results, SD= 0.611) and this only occurred in two cases in the co-located condition. There were no instances recorded for search results viewed collaboratively in the distributed setting. Participants were also observed viewing search results their partners were viewing (using the "past search" feature). This only occurred in the distributed setting an average of (0.14 times, SD= 0.36) by VI participants and an average of (0.21 times, SD= 0.80) by sighted participants.

A number of differences between the two studies were observed which suggests the influence of the ACSZ interface. In study 2, the average number of search results explored by both sighted and VI participants was

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

smaller in both conditions than in study 1 (Al-Thani et al., 2016). In table 5, we also observed the time spent by participants on each of the stages of IS. Participants spent less time browsing websites in study 2 than in study 1. In fact, the difference in the time spent browsing web sites by VI participants in study 2 was statistically significant across both conditions, as shown in table 6. Two factors seem likely to be behind this difference in behaviour. Firstly, the way the ACSZ interface was designed influences search behavior. As previously discussed, the participants preferred not to leave the search result page.

> **Finding 5-** The ACSZ interface design 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 were interacting with a shared workspace. The time spent managing retrieved information in study 2 was longer in comparison to the time spent managing retrieved information in study 1(Al-Thani et al., 2016).

Unlike study 1, there were only two pieces of evidence that collaboration occurred in the results exploration stage in study 2. In study 1, VI participants asked their sighted partners either to collaboratively explore search results for the pair to make sense of information together, or to act as an assistant to review the information more efficiently (Al-Thani et al., 2016). One reason for the disappearance of this behaviour in study 2 may be the way ACSZ is designed. ACSZ has features that allow 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 search" drop down list, view their partner's search results and discuss these with them.

> **Finding 6-** Having the ability to view team members' search results influenced the ability of the participants to collaborate in making sense of retrieved information.

Query reformulation: It was observed that this stage was undertaken individually. In the co-located condition, the average number of times a query was reformulated by VI participants was (0.35 times, SD= 0.633), and the average number of times queries were reformulated by sighted participants was (1.23 times, SD= 1.58). In the distributed condition, the average number of times a query was reformulated by VI participants was (0.5 times, SD= 0.64) and the average number of times a query was reformulated by sighted participants was (1.38 times, SD= 1.85).

Search results management: In study 2 the participants needed to create a structure (folders) into which retrieved information could be saved, and then having retrieved information, they had to "add post" and/or "save link". The only stage that was performed collaboratively in study 2 was the management of retrieved search results. The presence of a shared workspace clearly encouraged participants to perform search results management collaboratively. To explore the completeness of information stored, we reviewed the information stored by each participant and verified that each piece of information retrieved had 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 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.

The time spent managing information in study 2 was much longer than the time spent managing information in study 1. In study 2, the participants had a shared space to manage information in which they spent time and effort in organizing the information, while in study 1 the retrieved information was merely stored in a document or exchanged via chat messages or emails. Thus much less time was spent using communication tools in study 2 than in study 1.

	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][6]	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 5. Time spent in each stage in both conditions in minutes. (Average [SD]).

		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 6. Comparison between time spent browsing websites in studies 1 and 2 in minutes. (Average [SD]).

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

In the task specification, participants were asked to work together, but they were not explicitly asked to produce a shared outcome. In study 2, all pairs discussed their work and collaborated to form a shared result and thus after study 2, they were left with a shared outcome. This shared outcome consisted of a set of shared results structured in a way that both partners were familiar with. 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 better structured, the information is much more findable and usable. In contrast, after the sessions in study 1, partners were 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 (Al-Thani et al., 2016). The participants preferred the way the results were organized and accessed in study 2, as both team members had access to all the results of the CCIS process. In contrast, there was nothing in the process in study 1 to ensure equal sharing of the results within an agreed common structure.

> **Finding 7-** The interface encouraged participants to create a shared structure containing the results of the CCIS 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 that team members will know how far their partners have progressed in the CCIS process, and will have had the opportunity to examine results retrieved by their partner.

RQ 4: 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, RQ3, looked into evidence of the ACSZ system's effect on the stages of IS, this question explores approaches employed at the only stage that was performed collaboratively. To answer this question, we looked into the ways the participants employed the interface features to structure the retrieved search results. The participants used 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 participants spent slightly more time on this activity than their sighted partners, as shown in table 5. This slight difference may be due to the serial nature of screen readers and to web form accessibility navigation issues that the VI participants faced when adding posts to folders. In the pre-study training sessions, a number of VI participants experienced difficulties when filling in the "add post" form. Another issue the participants encountered, detected in the accessibility review, was the lack of alternative text for form controls; two edit boxes to be filled when adding a post were not labelled, which caused confusion. During training, VI participants highlighted that this was the hardest component to interact with. However one VI participant mentioned that he "*usually would get around such an issue with time*", principally by remembering the number and order of controls on the form.

In study 2, ACSZ enforced a certain approach to structuring information, which consisted of creating folders and storing retrieved information in them, thus allowing the users to store and structure the information retrieved in a two-level hierarchy. A number of approaches were observed in relation to how retrieved information was actually stored and structured. 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 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 noticed the more structured approach being used by her partner, and after completing the first sub-task, she started to follow a more structured approach when creating folders. Each created folder was dedicated to a category of information retrieved. These categories included travel booking, accommodation, dining and activities.

Participants differed in the way they used the interface features to store information in the folders. The participants used the interface features to structure and store the retrieved information as follows:

1. Using one specific feature to store each piece of information in the folder (for example, adding a post or saving a link). The information was stored in a two-level hierarchical structure (folder level and post level). This pattern of behaviour was seen in the distributed condition in six pairs by 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 sessions by both the VI and sighted participants, and in eight sessions by the VI participants only.
2. Using two features to store one piece of information. Two patterns of behaviour were observed.
    a. The information was stored in a two-level hierarchical structure, where the participant would save a link and add a post that

contained 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 participants in these pairs. Figure 2 presents a screen capture that illustrates this approach.

b. The information was stored in a three-level hierarchical structure. The participant would save a link or add a post and then add a comment to it with the related details. 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. Figure 3 is a screen shot which demonstrates this approach

Additionally they used the "add a comment" 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 participants in these pairs. It was observed that once a participant developed a strategy for storing information, that participant would usually keep using the same strategy for each new piece of information found and was likely to repeat the same pattern in the next condition.

Finding 8- The design of the ACSZ interface led to a more structured approach to organizing information retrieved, although within this overall approach, a number of individual variations were still observed.

The majority of VI users used one specific feature to store each 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 the effect of slowing down users' performance. Hence in order for VI partners to be efficient in looking for information, they tended to use one preferred interface feature to store the information retrieved, particularly if that method involved few steps, which saving a link did. Secondly, the web accessibility issues reported using the ""add post"" feature discussed had a major effect in making this feature less popular as seen in table 7.

Finding 9- VI and sighted participants differed in the ways they stored information. It can be deduced that the accessibility of interface components and the workload associated with a particular storage strategy can affect the VI user's choice of approach.

	VI Participants		Sighted Participants	
	Co-located Condition	Distributed Condition	Co-located Condition	Distributed Condition
Save Link	3.64 [2.95]	3.07 [2.84]	2.53 [2.25][7]	3.92 [2.55]
Add Post	0.71 [1.2]	1.0 [1.56]	2.0 [2.28]	2.42 [2.07]

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

Table 7. Number of times the features were used in each condition. (Average [SD])

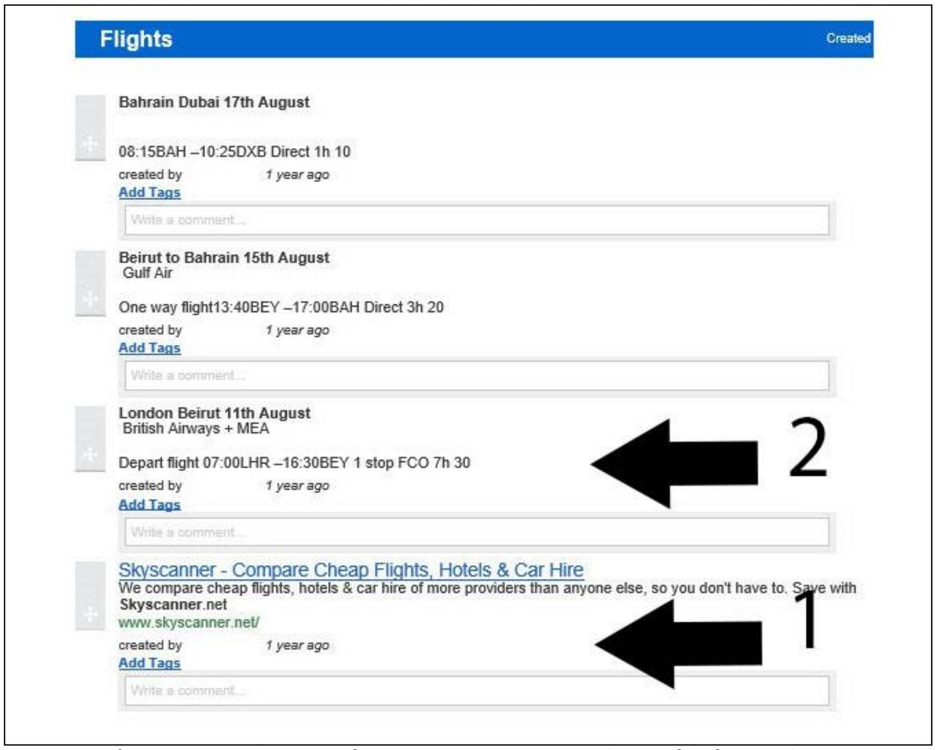

Figure 2. Using two features to store one piece of information.

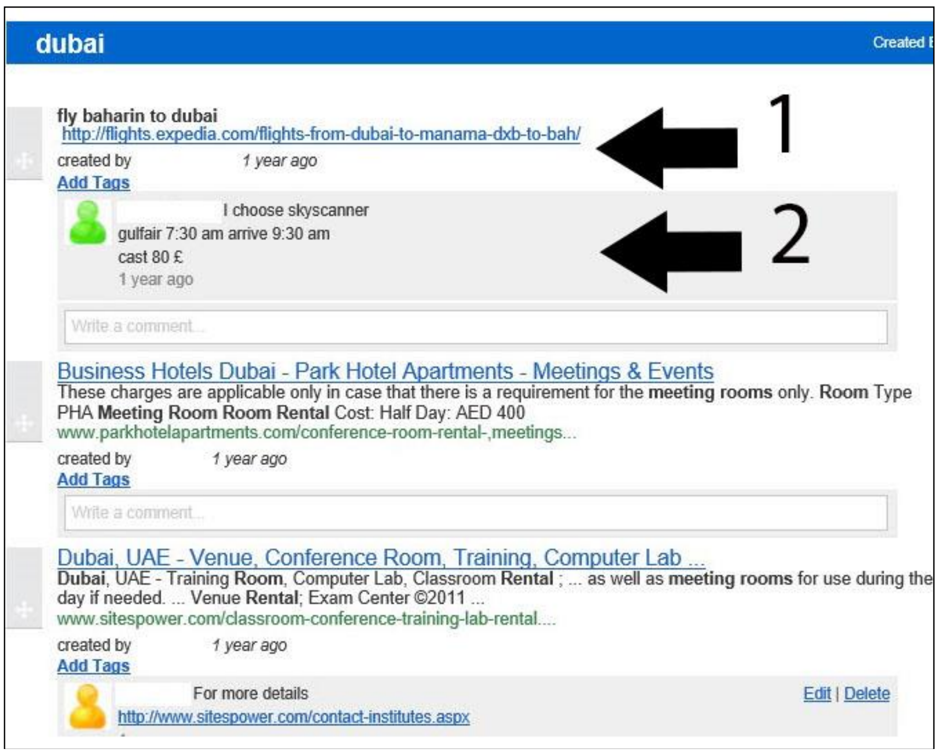

Figure 3. A three-level hierarchy structure.

6.2.2 *User interactions*

RQ5: Are the participants satisfied with the overall user experience?

Participants reported that their experience with the interface was pleasant and their satisfaction level was fairly high, as represented in table 8. The table shows the average answer and mode; mode is used here to provide the reader with an insight into the most popular answer. In the semi-structured interviews, 13 sighted and 10 VI participants expressed that even though it was their first time using the interface, they felt the process was easier than using separate applications, as in study 1. The benefit of providing an integrated solution that allowed users to organize and communicate retrieved information was highlighted by both VI and sighted participants. One VI participant commented *"it made them switch less between applications and save more time"*. Another VI participant stated, *"it's certainly easier than launching my email client and sending an email multiple times during a session"*.

As ACSZ provided an integrated solution, both VI and sighted participants spent significantly less time switching from one application to another in study 2. Table 9 shows the scores of a related t-test for the 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 details of the collaborative search task had to be referenced).

> **Finding 10-** 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 CCIS tasks.

User Satisfaction Level	VI Participants	Sighted Participants
	Average [SD](Mode)	Average [SD](Mode)
The Interface Ease of Use	7.07 [1.43](8)	8.28[1.63](10)
The Interface Accessibility	6.92 [1.77](8)	-

Table 8. Satisfaction levels with the usability and accessibility of ACSZ. (Average out of 10).

	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 9. Comparison between time spent switching from one application to another in studies 1 and 2 in minutes.

In the post-study interviews, the importance of training and learning through practice was highlighted by four VI participants. One participant commented that it is "*just about practicing how to use it*". Another participant pointed out that "*it would be easier once we get up and running with it*". He commented, "*The learning curve kind of slowed me down. However, that is a matter of getting used to it. If I had more training and time I would have done better*".

6.2.3 VI users' interactions with the features added specifically for accessibility

Despite being an interface not originally designed according to accessibility standards, as reported in section 3, there were very few issues recorded, and the time spent resolving these was very limited and did not substantially affect either the process or the performance of the participants. In this section, we examine VI users' interactions in relation to the accessibility enhancements we made to the interface.

RQ6: How did VI users interact with the awareness and navigation enhancements made?

The most popular and well-received enhancements were the shortcut keys to hear the chat messages, the PlaceMarkers and the "new chat message" alerts. Each of these features falls into one of two categories: awareness enhancements and navigation enhancements. To answer RQ6, we will discuss thoroughly the use of the enhancements, their effects on the user interaction and the participants' feedback.

In terms of awareness enhancements, two notification alerts were available. However, participants felt more satisfied with the "new chat message" alert than with the new post alert. Following the study, we asked participants to rate how satisfied they were with the two notification alerts and the JAWS script commands, which formed part of the enhancements made (described in section 3.2).

The average satisfaction level with the "new chat message" alert (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, one VI participant said that he *"simply did not feel the need to use it"*. Another VI participant stated, *"the message was clear to me"*. One participant said that when he needed an update about posts in folders he would usually navigate to the recent activity region. Thus, according to the post-study interviews, 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 was easier and quicker to navigate to as it is always available in the ACSZ interface. Secondly, and more importantly, it provides an overview of all the activities that have taken place in the project.

To assist VI users' navigation, there were two main enhancements: a chat messages keyboard shortcut and JAWS PlaceMarkers. The keyboard command for users to hear the chat messages allowed VI participants to quickly access the chat messages and avoid tedious navigation to reach the team chat component. 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) 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 hot keys to perform different actions in the interface. We asked the participants who did not use the feature the reasons they chose not to use it. Three participants 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 said that they simply forgot this feature was available.

The perceived value of the JAWS PlaceMarkers was highly dependent on the users' previous experience, as the consistency of PlaceMarkers varies depending on how dynamic the web content is. The users' expectations of these depended on whether they had previously used PlaceMarkers with dynamic content. Therefore there were differences in the average number of times PlaceMarkers were used to access each component as seen in table 10. The PlaceMarkers for team chat and recent activities tended to get displaced, therefore, the average number of times they were used was much lower than the average number of times PlaceMarkers were used to access the folders or the search engine. Even though PlaceMarkers had the displacement issue, participants found them very useful. One participant pointed out, *"it made navigating to parts of the interface much easier"*. In fact, their satisfaction level was very high (9 out of 10). 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*".

Finding 11- Hot keys were important in allowing VI users to perform certain tasks more efficiently

Finding 12- PlaceMarkers improved VI user's experience and presented an alternative, easier way to reach the major components of the interface.

	Co-located Condition		Distributed Condition	
	Number of Participants	Average [SD]	Number of Participants	Average [SD]
Folders	8	3.12 [2.23]	6	4.16 [2.78]
Search	7	3.57 [1.51]	9	5.55 [2.6]
Team Chat	2	2 [1.41]	3	3 [2.64]
Recent Activity	3	1.66 [1.15]	2	3 [0.0]

Table 10. Summary of times PlaceMarkers were employed.

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 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 table 7. VI users encountered form accessibility and navigation issues when filling in the "add post" form (the other means of storing information).

Moreover VI users favoured 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, as seen in table 4. When checking their partner's posts, two approaches were observed. As discussed in RQ3, to facilitate awareness, participants would navigate to either the recent activity region or the folders area. 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. Two sighted and two VI participants employed a combination of two approaches in the co-located setting, while six sighted participants and two VI participants employed a combination of two approaches in the distributed setting. The majority of participants preferred to use one approach (12 sighted participants and 12 VI participants in the co-located condition and eight sighted and 12 VI participants in the distributed condition).

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 was 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. This difference may be due to two reasons. Firstly, the serial nature of speech in screen readers can generally slow down the whole process of navigation and interaction with the web page interface. Secondly, the fact that VI participants preferred viewing the recent activity region more often than their sighted partners meant that they got the awareness and overview information they needed from there without needing to navigate between individual folders.

> **Finding 13-** VI users experienced issues when attempting to reach certain components or features because ACSZ is based on the SearchTeam website, which was designed with only sighted users in mind.

> **Finding 14-** VI users greatly benefited from the overview of recent activities provided by the interface, as it was straightforward to access this component.

7. 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 note here that in study 2, we employed one particular system, the only one of which we are aware that provides accessible CCIS, therefore we are only able to 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 CCIS process and their relevance to the use of a mainstream CIS system in a cross-modal context.

7.1. 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 (Al-Thani et al., 2016). This has allowed us to test their validity in supporting CCIS activities in study 2 and to base the following design suggestions on the findings of study 2 discussed earlier in this paper. This section presents the design suggestions that support the CCIS process and also revisits and updates the related design recommendations discussed in (Al-Thani et al., 2016).

7.1.1. Providing an overview of the information presented

The findings in study 2 (Findings 4 and 14) 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 (Al-Thani et al., 2016). The user then has the option to zoom-in on the desired information whether it is a search results page or workspace awareness information (which ACSZ partially provides through its recent activity region). 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.

> **Design suggestion 2-** Add mechanisms for categorising, filtering and clustering awareness information made available to make the process of navigating easier.

7.1.2. Providing an integrated interface

In the design suggestions (Al-Thani et al., 2016) we highlighted the potential of having an integrated solution that allows collaborators to keep track of information encountered, be aware of updates in the shared workspace, 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 workload 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 1.

7.1.3. Supporting group and workspace awareness

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 to ask group members explicitly about their activities 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.

As we have seen in the findings from study 2 (Finding 3), implicitly providing workspace awareness information through ACSZ features decreased the amount of information exchanged between collaborators. This helped participant pairs to reduce effort in reporting their contributions and progress. This concurs with early findings in the field of CSCW that confirmed that the availability of passive (implicit) workspace awareness information could enhance team members' coordination and performance (Dourish and Bellotti, 1992).

> **Design suggestion 3-** Provide users with an equal combination of group and workspace awareness information. Group awareness information includes query terms entered, search results pages viewed and websites being browsed. Workplace awareness information includes all updates that have been made in the shared workspace.

7.1.4. Improving the type and availability of awareness information

The findings from study 2 revealed that the type and availability of awareness information could impact users' experience, coordination effort and performance. In a cross-modal context, 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 4-** 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 4 and 14). Participants were also observed viewing "past search" to update their awareness of the query terms used by their partner (Finding 6). Even though a user would know when a change had 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 tended 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 easily allows collaborators to have an overview of shared workspace and group progress information when needed. A CCIS interface designer can achieve this by providing a place where such information is stored persistently.

> **Design suggestion 5-** Provide users with a command that allows them to navigate easily to a place where they can get an overview of awareness information of different activities in the CCIS process and shared workspace.

7.1.5. Multimodal representation of awareness information

While as discussed above, cross-modality is important, it was also observed that having a multi-modal representation of 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 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).

> **Design suggestion 6-** 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 multi-modally, 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.

7.2. 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 utilising available resources and access tool settings to improve the accessibility of a mainstream CIS interface 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.

7.2.1. Minimising the effects of the access tool on the strategies considered when interacting with the tools

As reported in study 1 (Al-Thani et al., 2013) participants divided the tasks in such 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 effect was also apparent even when participants were using the features of the interface. The average number of times sighted users created folders in the shared workplace was greater. Delegating tasks to the sighted user that were inaccessible or required extra effort by VI users allowed the VI user to put more effort into the search task.

> **Design suggestion 7-** 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.

7.2.2. 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 the source code of SearchTeam. Even though the use of hot keys was limited, it was very well received (Finding 11). 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 could help users navigate to a component or perform an action certainly enhanced VI user's performance and user experience. If the original design of the SearchTeam system had made full use of HTML headings, the capacity for improved usability using hot keys would have been exploited further.

> **Design suggestion 8**- Assign hot keys to assist navigation to features that the designer anticipates that the user would frequently use.

7.2.3. Improving navigation experience using an access tool

We introduced PlaceMarkers, which allowed VI users to navigate easily to the major components in the interface. From (Findings 11 and 12) it can be deduced that users benefited from this in two respects. 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 at the beginning of the task understanding the structure of the web page. Furthermore, the use of PlaceMarkers provided VI users with a consistent view of the four main components of the ACSZ web page. By using PlaceMarkers, participants were able to navigate quickly to specific interface components, which improved their performance and navigation experience.

> **Design suggestion 9-** Use PlaceMarkers or scripting features to assist users to navigate quickly to landmarks within a web-based interface.

8. CONCLUSIONS

This article provides an in-depth discussion about what happens to the process of CCIS when a tool is introduced specifically to support it. 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 compared this with the use of a dedicated, accessible interface. The findings aimed to answer the research questions from both a collaboration-focused perspective and an individual user-focused perspective. From the collaborative-focused perspective, the study results show that the availability of awareness features enabled users to put less effort into coordination, and improved their task performance. This contributes knowledge to the field of CCIS system design. From the individual user-focused perspective, the results reveal the positive effects of interface features on users' experience and performance. The study also provides evidence that VI users benefit 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 carefully considered 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.

This article concludes with a compilation of a set of design suggestions for the inclusive design of CIS systems. There is very limited work in the field of cross-modal web interaction; the work of Murphy (2007) 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 of studies 1 and 2, provide a significant contribution to the fields of CIS, cross-modal web interaction and inclusive design.

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