EXPLORING THE POTENTIAL OF GROUPWARE FOR REMOTE COLLABORATION: A USER STUDY ON REMOTE DECISION-MAKING

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ABSTRACT

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The popularity of remote work has increased dramatically after the COVID-19 pandemic due to its flexibility and cost-effectiveness. Today, numerous professionals employ videoconferencing to perform their daily tasks in the workplace. However, the widespread adoption of videoconferencing has introduced several new challenges, particularly originating from the extended use of such tools. Existing literature reports that constant users of videoconferencing tools experience increased workload, fatigue, and decreased creative activity. Given the increased popularity of remote work and the challenges described, exploring alternatives to videoconferencing for remote work is crucial. This study examines groupware tools as a potential alternative to videoconferencing to enhance remote collaboration.

For this work, we developed a groupware application and conducted a comparative case study with 60 university students to assess collaboration under three conditions: on-site collaboration, remote collaboration with videoconferencing, and remote collaboration with groupware. According to post-task questionnaires, groupware provides a superior user experience for remote collaboration compared to videoconferencing. Task completion times varied among the conditions, with the on-site condition demonstrating faster task completion times than the remote conditions. Crucially, an analysis of the task responses suggests that groupware can effectively simulate the decision-making dynamics of on-site environments. Conversely, videoconferencing demonstrated no such effect and negatively influenced the participants' decision-making processes.

ÖZET

UZAKTAN İŞ BİRLİĞİ İÇİN GRUP YAZILIMININ POTANSİYELİNİ KEŞFETMEK: UZAKTAN KARAR VERME ÜZERİNE BİR KULLANICI ÇALIŞMASI

M. FATİH ÖZTANK

BİLGİSAYAR BİLİMİ VE MÜHENDİSLİĞİ YÜKSEK LİSANS TEZİ, HAZİRAN 2024

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COVID-19 pandemisi ile birlikte sağladığı esneklik ve düşük maliyeti nedeniyle uzaktan çalışmanın popülerliği önemli ölçüde arttı. Günümüzde, birçok profesyonel iş yerinde günlük görevlerini uzaktan yerine getirebilmek için video konferans araçlarını kullanmaktadır. Ancak, video konferansın yaygın olarak benimsenmesi, özellikle bu tür araçların uzun süreli kullanımından kaynaklanan yeni problemleri de beraberinde getirdi. Mevcut literatür, video konferans araçlarının sürekli kullanımında kullanıcılarda iş yükünün arttığını, yorgunluk yaşattığını ve yaratıcı faaliyetlerinin azalttığını bildirmektedir. Uzaktan çalışmanın artan popüleritesi ve bahsedilen zorluklar göz önüne alındığında, uzaktan çalışma için video konferansa alternatifler araştırmak büyük önem arz etmektedir. Bu çalışma, uzaktan iş birliğini geliştirmek için video konferansa potansiyel bir alternatif olarak grup yazılımı araçlarını incelemektedir.

Bu çalışma için bir grup yazılımı uygulaması geliştirilmiş ve üç koşul altında iş birliğini değerlendirmek için 60 üniversite öğrencisi ile karşılaştırmalı bir kullanıcı çalışması yürütülmüştür: aynı konumda iş birliği, video konferans ile uzaktan iş birliği ve grup yazılımı ile uzaktan iş birliği. Çalışma sonrası yapılan kullanıcı anketlerine göre, grup yazılımı, video konferansa kıyasla uzaktan iş birliği için daha üstün bir kullanıcı deneyimi sunmaktadır. Görev tamamlama süreleri koşullar arasında

farklılık göstermiş olup, aynı konumda yapılan işbirliği, uzaktan koşullara göre daha hızlı görev tamamlama süreleri göstermiştir. En önemlisi, görev yanıtlarının analizi, grup yazılımının kullanıcıların aynı konumda olduğu koşullardaki karar verme dinamiklerini etkili bir şekilde simüle edebildiğini göstermektedir. Buna karşılık, video konferans böyle bir etki göstermemiş ve katılımcıların karar verme süreçlerini olumsuz etkilemiştir.

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"Push It To The Limit"

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1. INTRODUCTION

Although the impacts of the COVID-19 pandemic have long gone, many businesses and educational institutions continue to utilize remote work due to its flexibility, cost savings, and higher user satisfaction [8; 36]. Videoconferencing tools like Zoom [92], Google Meet [43], and Microsoft Teams [70] are being widely used in remote working environments, recognized for their robust videoconferencing and screen-sharing features. During the pandemic, Zoom had more than 300 million daily active meeting participants by December 2020 [51]. Likewise, MS Teams also saw a dramatic increase in the number of users, increasing from 20 million users in November 2019 to 270 million users by 2022 [25].

This transition to remote work has yielded notable benefits [2; 36], but has also introduced new challenges, particularly originating from technical and social limitations of remote work and videoconferencing tools. These limitations frequently arise from the restricted exchange of non-verbal cues among the collaborators and the blurred boundary between the home and work life, which reduces participant engagement during remote meetings [59; 78]. Since 2020, numerous studies have associated higher fatigue and workload with videoconferencing due to these limitations [13; 18; 31; 34; 57; 63; 72].

To address these limitations and foster a more engaging environment for remote collaboration, the literature has explored the application of head-mounted displays (HMDs) and immersive virtual reality (VR) technologies [2; 19]. In a user study that explores the potential of VR technologies for remote work, Abramczuk et al. [2] conduct a seven-week user study on remote teams by using Horizon Workrooms [68] as an alternative to videoconferencing. Authors reported that VR meetings present more advantages, and participants were more focused on the meeting when compared to videoconferencing. However, the authors also highlight challenges with the current VR technologies based on their observations. These challenges are particularly originating from the limited public accessibility of XR tools, as well as issues originating from prolonged use of these tools, such as motion sickness and eye fatigue [2; 73].

As an alternative to XR technologies, Computer Supported Cooperative Work (CSCW) literature proposed groupware implementations that do not necessitate the use of HMDs or VR technologies [12; 10; 81]. However, contrary to XR technologies, groupware received relatively little attention from the current literature as a remote collaboration tool. Therefore, there is a scarcity of literature discussing the potential of groupware as a remote collaboration medium. Given the increasing popularity of remote work, it is crucial to explore alternative approaches for remote collaboration to enable a more convenient remote collaboration experience.

This thesis is an exploratory attempt to discover the potential of groupware tools as a remote collaboration tool. For our study, we implemented a groupware system and designed a comparative case study that simulates a collaborative decision-making process. The case study was structured to assess the collaboration process under three distinct conditions: on-site collaboration, remote collaboration with a videoconferencing tool, and remote collaboration using the implemented groupware.

Our user study with 60 participants revealed key insights into collaboration dynamics across various platforms. Notably, analyzing the correctness of the task responses demonstrated that remote collaboration through groupware resulted in significantly more precise decisions than those made through videoconferencing. An analysis of task completion times revealed no notable differences across remote conditions, while significant differences were observed between the task completion times of on-site and remote conditions. Additionally, according to the post-task questionnaire results, groupware demonstrated a superior user experience when compared to both on-site and videoconferencing conditions. These findings highlight the intricate relationship between collaboration platforms and underscore the potential of groupware as a medium for remote collaboration.

The remainder of this thesis is structured as follows: Chapter 2 explores the related work, with a particular focus on the current challenges in videoconferencing and remote work and proposed groupware implementations in the literature. Chapter 3 introduces our developed groupware system, Collaborative Atlas. Chapter 4 details the design and evaluation approach of our comparative user study. Chapter 5 presents the findings from the user study and discusses their implications. Chapter 6 outlines the limitations of this study and suggests directions for future research. Lastly, Chapter 7 provides a conclusion to this thesis.

2. RELATED WORK

This chapter examines the existing literature on remote work and groupware. Section 2.1 provides an in-depth analysis of studies addressing the challenges associated with videoconferencing and remote work. Section 2.2 offers a brief introduction to the field of collaborative visualization. Finally, Section 2.3 explores current literature on groupware, highlighting numerous implementations particularly designed for collaborative visual analytics.

2.1 Videoconferencing and Remote Work

Since the dramatic shift to remote work, the literature has been discussing the impact of this transition on the routine users of videoconferencing tools. A review of the existing literature on the effects of videoconferencing identifies three predominant issues: an increase in stress and fatigue due to extensive use of videoconferencing platforms [1; 30; 33; 78], often referred to as *Zoom Fatigue* or *Videoconferencing Fatigue*, a decline in creativity and idea generation [23; 50; 41; 61], and increased distraction and interference during remote meetings caused by the blurring of boundaries between personal life and work [59].

The concept of "Videoconferencing Fatigue (VCF)" has been extensively researched, with efforts to establish a precise definition of the phenomenon [1; 30; 33] and to identify its underlying causes [13; 29; 78]. The literature suggests that the primary causes of this phenomenon can be summarised under five main points, as detailed in Table 2.1: asynchronicity of communication, multitasking during videoconferencing, lack of non-verbal cues, increased self-awareness, and the unnatural interaction with multiple faces [13; 78].

In addition to establishing definitions, the literature has also conducted numerous

Problem	Explanation
Asynchronous communication	Network delays experienced during videoconferencing may cause increased cognitive load due to the additional effort by the brain to restore synchronicity [78].
Multitasking opportunities	Additional stimuli occurring during videoconferencing may encourage participants to switch between multiple tasks if they are not fully engaged in the collaboration, resulting in up to %40 loss of their productive time [78; 39].
Lack of non-verbal cues	Lack of body language and eye contact leads to coordination difficulties between participants, resulting in inaccurate emotion perceptions and higher cognitive effort [78; 13].
Increased self-awareness	While videoconferencing, participants are likely to see their faces in a window on the screen if their cameras are enabled. Constantly perceiving one's own video can disrupt the automatic processes that are crucial for effective communication [78; 13].
Close distance eye gaze between participants	Videoconferencing enforces an unnatural interaction between participants since it displays the faces of the collaborators, too close to the screen, potentially increasing arousal and stress [78; 13]

Table 2.1 Root Causes of Videoconferencing Fatigue

user studies to examine the impact of VCF on regular users of videoconferencing tools [18; 31; 57; 63; 72]. In a study involving employees of a global technology company, Bergmann et al. [18] surveyed 849 participants to explore the tensions between work effectiveness and sociality. Their findings suggest that the solution to VCF lies not in the technical realm but rather in enabling a more socially engaging remote work environment. Meanwhile, another study by Anh, Whelan, and Umair [57] surveyed 429 daily users of videoconferencing tools to gain a deeper understanding of VCF. According to their results, authors argue that the primary cause of VCF is usability problems within the videoconferencing tools, such as the difficulty in locating crucial buttons on the screen.

In a subsequent study, Luebstorf et al. [63] interviewed nearly 400 employees from the US and Germany to understand the stressors of videoconferencing and remote work. Based on their findings, the authors found early meeting phases and multitasking to be the primary stressors of videoconferencing. Interestingly, the authors also point out that camera usage was pivotal for a good virtual meeting experience, according to the interviewees. Although the literature often positively correlates VCF with camera usage [13; 34; 78], this study stated the opposite. The authors attributed this contradiction to their interviewee profile, which mainly consisted of meeting leaders. This distinction could suggest that different roles during a remote meeting may have different perspectives on VCF.

Beyond Zoom Fatigue, videoconferencing presents additional challenges, particularly affecting creative processes [41; 50]. In their work, Brucks and Levav highlight that videoconferencing may inhibit idea creation [23]. According to the authors, videoconferencing focuses communicators on a screen, prompting a narrower cognitive focus and hampering idea creation. Supporting this viewpoint, a subsequent study [61] confirmed Brucks and Levav's assertions. In their research, authors compared the outcomes of on-site and remote research teams, finding that remote teams were consistently less likely to achieve groundbreaking discoveries compared to their on-site colleagues.

The reduced information exchange among the remote workers can also explain the decreased creative activity. A study [91] conducted on Microsoft employees in the first half of 2020 demonstrates a decrease in synchronous communication and an increase in asynchronous communication among employees. The authors claim that this results in fewer ideas being exchanged across the company since the collaboration network of workers has become more static and insulated. A similar conclusion has also been made by Lin et al. [61], noting that the decline in face-to-face communication has led to reduced information exchange, subsequently hindering creative activity.

In addition to VCF, remote work introduced many different challenges, particularly originating from the blurred line between personal life and work [54; 59; 80; 85; 90; 93]. In their study investigating the primary factors of distraction during videoconferencing, Lee et al. [59] propose a unified framework to group common distractors under five categories, including the environment around the user and usability problems in the videoconferencing medium. In another study, Reyes et al. [80] surveyed 1285 employees to investigate the relationship between remote work, work stress, and work-life balance across Latin America. Their findings revealed that remote work during the pandemic increased the perceived stress and reduced work-life balance and work satisfaction. Contrary to adverse effects, authors also report increased productivity and engagement, but only if remote work does not stretch over extended periods.

Despite its drawbacks, videoconferencing has been widely adopted for remotely conducting daily activities across various domains, including education [62], healthcare [35], and business [18; 21]. In our research, we focused our user study on the visual analytics domain, where participants must interpret geographical visualizations and derive meaningful insights collaboratively. We selected this domain due to the growing need for collaboration prompted by the advent of more extensive and increasingly complex datasets [38; 52].

2.2 Collaborative Visualization

Due to the increasing complexity of the problems analysts face, collaboration is named one of the grand challenges for visual analytics [38]. The term "Collaborative Visualization" is widely defined by the existing literature [53; 52; 60; 74] with a consensus that it applies to "visualizations enabling multiple stakeholders to elaborate on the visualized information."

Most of the literature on collaborative visualization is deeply interconnected with the CSCW literature, with numerous groupware implementations proposed to analyze large datasets collaboratively [4; 74; 81; 89]. On top of these implementations, some prior studies defined design considerations [47] and principles [20] to develop effective collaborative visualization systems. In their work, Heer and Agravala [47] elaborate on design considerations for collaborative visual analytics and emphasize that the primary goal should be to effectively parallelize work, facilitate mutual understanding, and reduce the costs of collaborative tasks. In a subsequent study, Bier, Card, and Bodnar [20] focus on a subset of the design considerations defined by Heer and Agravala [47]. The authors present five design guidelines for collaborative analysis and knowledge work in their study. These guidelines particularly support the sharing of the intermediate products of visual analysis.

2.3 Groupware For Remote Collaboration

The concept of "Groupware" emerged in the 1980s from the shared interests of researchers from diverse fields [44]. This term has been used to define software that allows multiple concurrent users to work on the same objective collaboratively [16; 75]. Since the emergence of the term, the literature has discussed various definitions of software that are considered groupware. Since the early 1990s, researchers have considered network file servers [56], version control systems [44], and email [56] as groupware. In the current terminology, however, groupware is often used for software that allows multiple collaborators to work on a shared view simultaneously.

The CSCW literature employs a space-time matrix (Table 2.2) to categorize the collaborative work into four categories [44; 52]. Among these categories, co-located collaborative visualizations have been extensively studied by incorporating multi-user tabletop interfaces [82; 88] or multi-device environments [49; 24]. Contrary to on-site collaboration, distributed collaboration has received relatively less attention from the literature.

	Same place (On-site)	Different place (Distributed)
Same time (Synchronous)	Face-to-face Tabletop interfaces, Multiple displays	Videoconferencing screen sharing
Different time (Asynchronous)	Shift work Bulletin boards	Email Blogs

Table 2.2 Space-time matrix of collaboration

Early collaborative visualization systems were based on multimedia sharing between collaborators [17; 7]. CEV, as outlined by Raje et al. in 1998 [74], is among the earlier groupware systems facilitating distributed collaboration. It enables real-time sharing of multimedia-based visualizations among collaborators. In their implementation, the authors implemented a manual synchronization logic where the leader user manually broadcasts its local view to other users. Although this approach provides a common view among participants, manually broadcasting the view can introduce extra mental workload and hinder collaboration [83]. In a subsequent study, Bajaj and Cutchin [14] propose their groupware for scientific visualization. Parallel to CEV [74], Bajaj and Cutchin used a similar concurrency control mechanism. However, unlike Raje et al., the authors utilized a much more advanced synchronization logic. In their implementation, any change performed to the global view by the leader user is propagated to the other users automatically.

With the advancements in web technologies, later studies extensively utilized web technologies for developing collaborative visualization systems. Sense.us [48] and Many Eyes [89] were among the first collaborative visualization systems allowing visualization of arbitrary datasets over the web. Sense.us [48] allowed commenting and annotating on visualizations of the US Census data, which was preloaded to the system. Building on this, Many Eyes [89] not only supported commenting and annotating on visualizations but also allowed users to upload their own data to the system. Despite these tools focused on asynchronous collaboration, they enhanced collaboration and paved the way for new opportunities in social analytics.

Future studies further utilized web technologies to create collaborative visualizations. Frameworks like PolyChrome [10], Munin [11], and Vistrates [12] have been developed for developing distributed collaboration interfaces. These frameworks facilitate groupware development by providing custom components synchronized by the application logic. Although these frameworks streamline groupware development, they suffer from compatibility challenges with the visualizations created without using these frameworks. To address this challenge, Schwab et al. [81] propose VisConnect, a web-based synchronous collaboration system that allows collaborative usage of most web-based SVG visualizations with minimal code changes. VisConnect synchronizes the low-level pointer events between collaborators to synchronize multiple views. To evaluate their study, the authors implemented three prototype applications using VisConnect and conducted a case study with one of the implemented applications. While the authors state that user feedback was mostly positive, it's worth noting that no comparative case study was performed to evaluate VisConnect against other groupware.

In addition to web technologies, numerous studies have employed external screens to enhance collaboration. SAGE [77] and its successor SAGE2 [66] are interfaces designed to facilitate both co-located and remote collaboration by leveraging large displays to display multiple networked applications on a common display. In a subsequent study, Alsaiari, Johnson, and Nishimoto introduced PolyVis [4], a cross-device framework built upon SAGE2 for collaborative visual analytics. In their work, the authors extend the capabilities of SAGE2 to support collaborative visual analytics by providing declarative visualizations for seamless migration of visualizations and implementing an operation transformation mechanism to maintain consistency between multiple devices. To evaluate PolyVis, the authors conducted a collaborative session with two field experts and discussed their feedback.

While one can argue that tools like Zoom and MS Teams can also be considered groupware because of the screen-sharing and remote control functionalities, these functionalities are insufficient to provide synchronous collaboration due to their high network requirements [26] and limited multi-pointer support [32].

3. COLLABORATIVE ATLAS

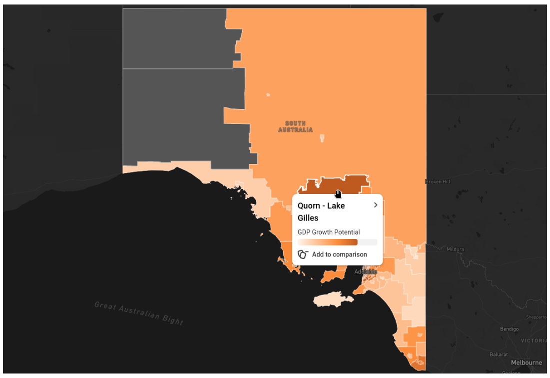
For our study, we implemented Collaborative Atlas (CA), a prototype groupware application designed for collaborative visual analytics. It is implemented using HTML, CSS, and JavaScript. CA allows the collaborative use of existing web-based visualizations with minimal code changes by synchronizing browser events. The architecture of CA encompasses a client application, which is developed as a standalone desktop application, and a server, which is a basic socket-based HTTP server. The client application handles the majority of functionalities to ensure a shared view shared among the participants. The client manages the event synchronization, concurrency control, and error handling to ensure a shared view. On the other hand, the server handles the communication among the separate client instances.

For the sake of this study, CA is employed alongside a geographic information visualization tool, Atlas of Opportunity [71].

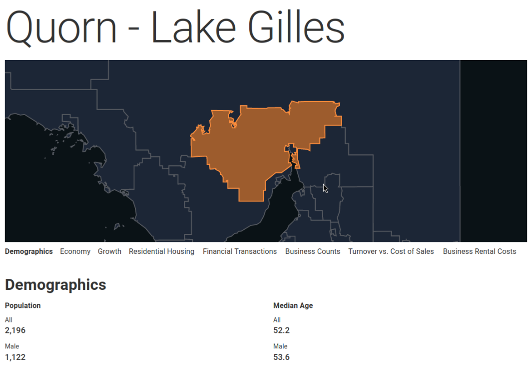
This chapter discusses our implemented groupware, Collaborative Atlas (CA), in detail. Section 3.1 introduces the Atlas of Opportunity and its possible use cases. Section 3.2 describes our design requirements and explains how each requirement is addressed in our implementation.

3.1 Atlas of Opportunity

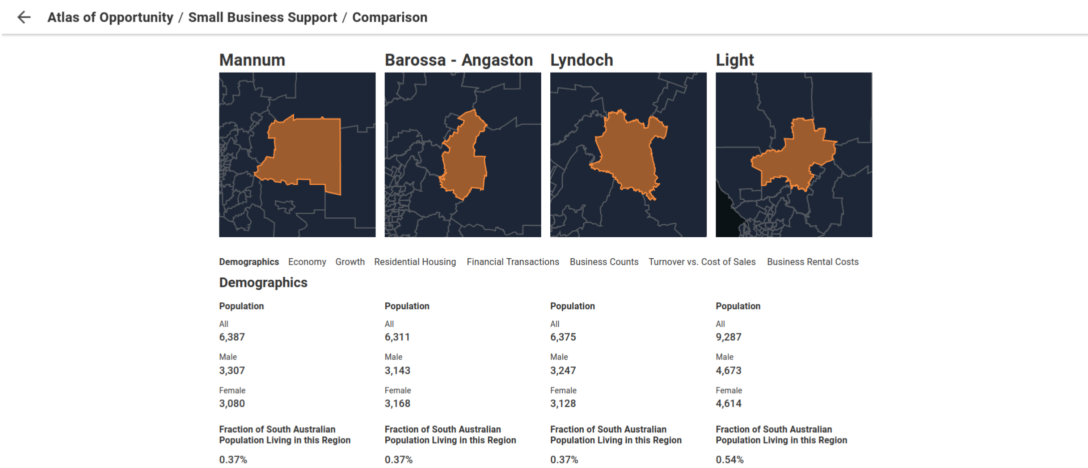
The Atlas of Opportunity (AoO) (Figure 3.1) is a web-based Geographic Information System (GIS) developed by a team of visual analytics researchers. It is designed to assist a wide range of users, including government officials, organizations, small and medium-sized businesses, and citizens, in making data-driven decisions. The AoO offers detailed insights into the socio-economic features of various Statistical Area Level 2 (SA2) regions within South Australia. A Statistical Area Level 2 (SA2) region is a medium-sized, usually about the size of a suburb, a general-purpose geographical area representing a community that interacts socially and economically [9]. By providing a detailed look at the socio-economic landscape of South Australia, AoO assists small business owners in planning more informed business strategies.



(a) The main page of the AoO.



(b) Details page of the selected region.



(c) Comparison page.

Figure 3.1 User interface of Atlas of Opportunity [71] web application.

The Atlas of Opportunity features an interactive map (Figure 3.1a) on its main page, allowing users to access data specific to each Statistical Area Level 2 (SA2) in South Australia. By selecting an SA2 region directly on the map, users are navigated to the selected region's details page (Figure 3.1b). This page displays the socio-economic data of the region and leverages multiple visualization techniques to present it effectively. Additionally, the Atlas offers a comparative function, enabling users to analyze the socio-economic features of multiple SA2 regions side by side (Figure 3.1c).

The AoO is intended to be used by a wide range of users. Although this thesis primarily addresses the application of AoO within small and medium-sized businesses, its potential applications extend beyond merely selecting an SA2 region for business decisions. For instance, government officials could utilize the AoO to examine demographic data pertaining to SA2 regions while issuing policies, or organizations could employ it to investigate patterns of economic growth and development across different SA2 regions.

3.2 Design Requirements

During the development of the CA, two primary requirements were taken into account. Firstly, the application needed to function as a groupware tool facilitating remote collaboration using everyday computers. Although groupware is an umbrella term encompassing various formats, including tabletop, multi-display, and desktop applications, our objective was to offer a more convenient remote collaboration experience without a need for additional hardware. Therefore, the CA should be implemented as a standalone application compatible with all major operating systems.

Our second requirement refers to the collaborative use of the underlying visualizations. This collaboration should go beyond a shared view, such as what screen-sharing provides, to allow several users to interact with the visualizations simultaneously. This can be accomplished by implementing a component for sharing user interactions. An interaction is described as any user-initiated event, such as mouse movements, element clicks, or page navigation.

While implementing an event-sharing functionality, one should consider cases where multiple users trigger an event simultaneously. These cases may result in unexpected behaviors if they are not properly addressed. For example, assume a scenario where *Alice* and *Bob* collaborate using CA. While collaborating, *Alice* navigates to the details page of an SA2 region. However, before *Bob's* client receives *Alice's* remote event, *Bob* also navigates to a different region's details page. In this situation, *Alice* and *Bob* would have different views. Consequently, collaboration is hindered.

The implemented system should not allow such cases to happen, and if such cases happen, it should resolve the conflict while ensuring the shared view among participants. To prevent such cases, CA is equipped with a mechanism to prevent any conflicts among the users.

3.2.1 Platform Specification

It is possible to develop an application compatible with all major operating systems by utilizing web technologies or cross-platform desktop application frameworks. Web technologies offer a native way to facilitate interaction with web-based visualizations; however, these interactions are generally limited due to security concerns. On the other hand, desktop applications are not subject to these limitations. However, they lack native capabilities to interact with web-based visualizations and require additional implementations to trigger user interactions [32].

To leverage the advantages of web technologies and desktop applications, the Electron framework[1] has been utilized for implementing CA. Electron is a framework that enables developers to build cross-platform desktop applications using web technologies such as HTML, CSS, and JavaScript. Using Electron, the AoO interface may be seamlessly integrated into CA without requiring additional configurations or meeting security constraints. Furthermore, applications developed with Electron can run on all major operating systems without requiring any further code modifications.

3.2.2 Event Sharing

Event sharing is crucial for enabling an interactable shared view among collaborators. When a collaborator interacts with the underlying visualizations, this interaction must be replicated across the instances of all participants. CA employs JS events and WebSockets to ensure a shared view among participants.

In our implementation, the client-side application manages the majority of the event-sharing logic. The client embeds the AoO interface within a custom iframe component (will be referred to as *iframe*). This component is responsible for listening to two types of events: Local events and remote events. Local events are defined as interactions performed by the user on their own instance, such as mouse events within the AoO interface, which are subsequently captured and handled by the iframe. Conversely, remote events refer to the interactions the remote users perform on their respective instances. The server broadcasts these remote events to all participants, and the iframe processes these remote events to replicate in the local

[1] https://www.electronjs.org/

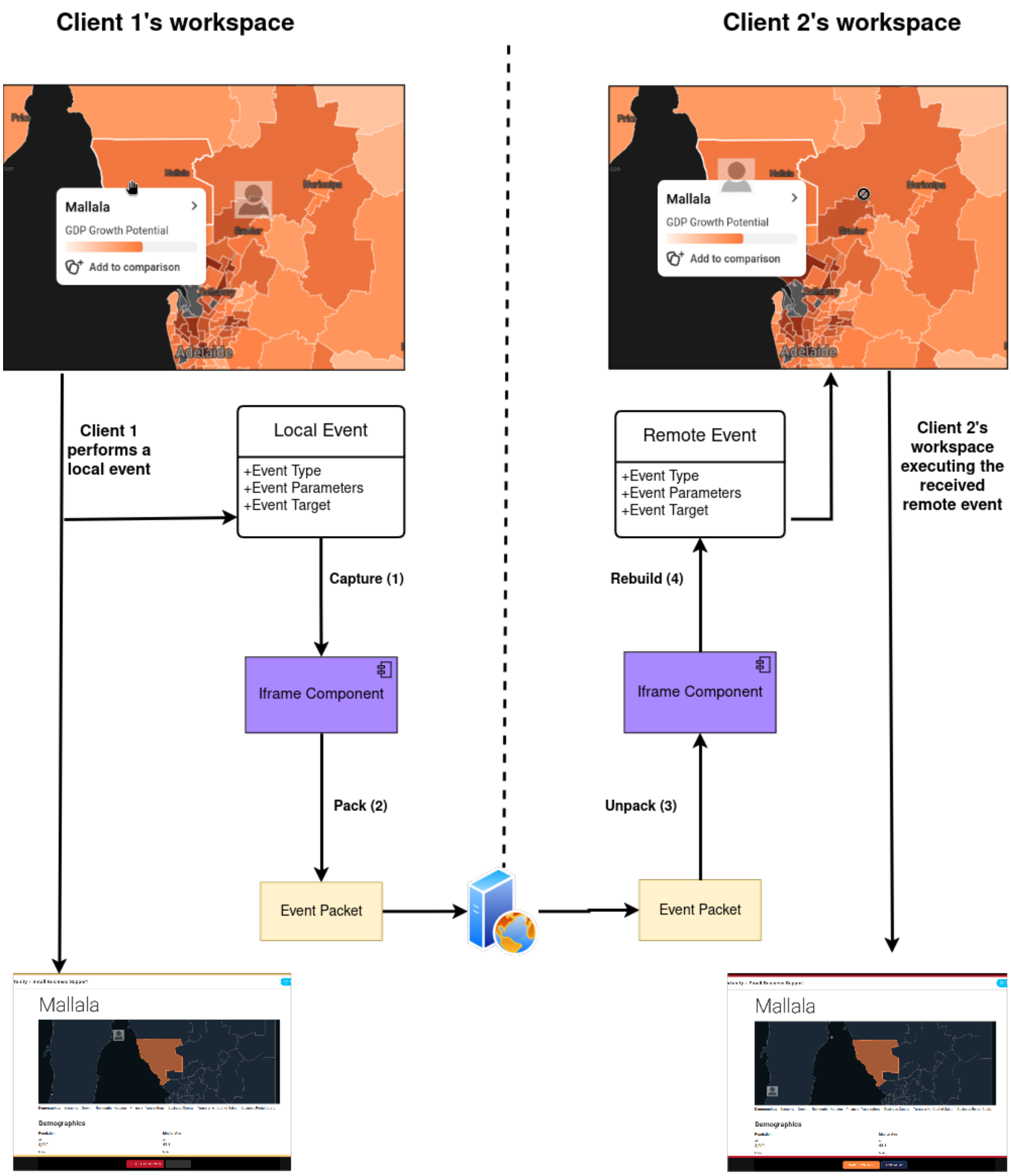


Figure 3.2 Demonstration of the event synchronization mechanism.

instance. An overview of the event synchronization logic can be found in Figure 3.2.

As shown in Figure 3.2, whenever a user performs a local event, the iframe **captures (1)** all necessary information to replicate this event and creates an **event packet (2)**. This packet is then sent to other clients. Upon receiving an event packet, the iframe **unpacks (3)** it, **reconstructs (4)** the same event and executes a corresponding remote event.

Underlying visualizations in the AoO interface are exclusively interacted with through mouse events. Therefore, we only focused on synchronizing the pointer-based JS events while implementing CA. Our implementation supports the following mouse events:

- **Mousemove**: Any user action that involves moving the mouse pointer.
- **Mousewheel**: Any user action that involves using the mouse wheel.
- **Mouseclick**: Any user action involving clicking an element with the mouse.

3.2.2.1 Mousemove

When a user moves their mouse, the iframe captures the pointer's final x and y coordinates relative to the dimensions of the AoO interface. These coordinates are then normalized according to the iframe's own dimensions to ensure proper collaboration across collaborators with different screen resolutions.

When iframe receives a remote mousemove event, it converts the x and y coordinates into the respective positions within the AoO interface. The iframe then renders an avatar of the user who triggered the remote event at the calculated coordinates. The avatars are utilized to streamline communication when participants wish to point out an element on the screen remotely.

Mousemove	
EventX	float
EventY	float

Figure 3.3 Mousemove event properties

3.2.2.2 Mousewheel

The mouse wheel is used to zoom in and out on the interactive map and scroll down and up on the details page. Whenever a mousewheel event is triggered, the iframe captures the event's coordinates, likewise the mousemove event. Additionally, the iframe captures the *deltaY* property of the wheel event, which represents the vertical scroll amount. When a remote mousewheel event is received, the identical event is built and executed using the received properties.

Mousewheel	
EventX	float
EventY	float
DeltaY	float

Figure 3.4 Mousewheel event properties

3.2.2.3 Mouseclick

When a user clicks on an element in the AoO interface, the iframe captures event coordinates and the XPath selector of the event target. When iframe receives a remote mouseclick event, it calculates the event target using the XPath selector. The coordinates of the event are utilized primarily when the XPath selector alone does not suffice to replicate the event accurately. For example, when a user clicks on an SA2 region in the interactive map, the XPath selector is insufficient to replicate the event since the map is designed as a single HTML element, and the result of the click action varies based on the coordinates of the mouse on the map. Depending on the mouse pointer's location, a click action may result in a different SA2 region being selected on the map.

Mouseclick	
EventX	float
EventY	float
EventTargetXPath	XPathSelector

Figure 3.5 Mouseclick event properties

3.2.3 Concurrency Control Mechanism

Event sharing is implemented based on two key assumptions: First, it assumes that all participants begin their collaborative session from an identical starting point. Second, it assumes that the outcomes of the local and remote events should not interfere with each other. In other words, while a user performing a local event, the iframe should only execute a remote event if that event does not change the view. Similarly, while a remote event is performing, a user should only be able to trigger an event that does not update the view. For example, a mousemove event does not update the view while mousewheel and mouseclick events update the view.

CA utilizes a global lock exchange to prevent possible conflicts. Global lock restricts the control of the interface to one participant (the *leader*) at a time. When a user obtains the global lock, other users are prevented from triggering events that modify the shared view. Users can click the "Enable Controls" button in the CA interface to obtain the lock.

The lock mechanism is implemented by utilizing an invisible div element. When the iframe is locked, this invisible div element is positioned on top of the iframe element. This div element intercepts mouse events, thereby preventing the underlying iframe from processing these events and blocking interaction with the interface beneath it. Additionally, similar to iframe, the div element listens to the mousemove events when the lock is active. This design allows users to utilize their avatars even when their interface is locked.

Although the global lock prevents possible conflicts between events, it also limits simultaneous access to the interface. This limitation may potentially interfere with the natural flow of communication among collaborators [83]. Prior work utilizes more sophisticated approaches such as element-based lock service [81] or timestamp-based event synchronization [10] to allow simultaneous access to the interface. In future studies, CA will implement these approaches to enhance the collaboration further.

3.2.4 Error Recovery

As stated in the previous section, event sharing assumes all participants preserve an identical view throughout the collaborative session. However, even with an event-sharing mechanism, the shared view can still be broken if network problems arise. Although these cases are extremely rare, CA is equipped with a basic error recovery mechanism against these situations.

AoO interface stores the state information in the page URL. Depending on whether the user is viewing the map or the details page, the URL can store two different state information:

- **Map**: x and y coordinates of the map, and the zoom amount.
- **Details page**: ID of the current SA2 region being viewed. If multiple regions are being compared, the URL stores the IDs of all compared regions.

During a session, the leader periodically broadcasts the URL of the AoO interface to all users. When iframe receives the URL, it compares the received URL with its own URL. If the URLs are not the same, the iframe automatically adjusts the local instance's URL and restores the shared view.

4. USER STUDY

To discover the potential of groupware tools as a remote collaboration medium, we designed a comparative user study by employing Zoom as a videoconferencing tool and Collaborative Atlas (CA) as groupware. In addition to remote conditions, we employed an on-site condition in our user study as ground truth to determine how close groupware emulates the on-site collaboration experience. For the user study, participants performed a task that imitates the real-world application of the Atlas of Opportunity (AoO). User study results had been compared within three collaboration conditions in terms of *effectiveness*, *efficiency*, and *satisfaction*.

This chapter provides an in-depth explanation of our user study design. Section 4.1 discusses the early stages of our research, which includes a preliminary study on immersive collaboration and a pilot study with an early version of CA. Section 4.2 provides a detailed explanation of the collaboration conditions and the user study task conducted by the participants. Lastly, Section 4.3 discusses the evaluation metrics used in this study.

4.1 Preliminary Studies

Throughout this study, we explored different approaches with our methodology. In the early stages of our research, we investigated the possible use of immersive reality technologies to enhance remote collaboration. However, this approach was abandoned due to technical limitations. In addition, we carried out a pilot study using an early version of CA to address the flaws in our study design and detect any possible bugs in CA's implementation.

4.1.1 Immersive Collaboration

During the early stages of our research, we investigated the potential of utilizing immersive reality technologies to improve remote collaboration. To assess the viability of such an approach, we developed a prototype immersive reality system that incorporates the AoO interface. Our prototype consisted of five main components: a solid surface (a table in our case) serving as the display for the shared view, a projector to project the shared view onto the table, a Microsoft Kinect [69] camera to capture user gestures at the table, large displays enabling collaborators to view each other, and a central server to coordinate the aforementioned components.

In contrast to CA, which integrates the shared view with the event synchronization logic, this implementation kept the shared view and synchronization logic in separate components. In this implementation, the Kinect camera was responsible for gesture recognition and transmitting the detected gestures to the central server. Once the server receives a gesture, a corresponding user action is triggered on the shared view of all collaborators.

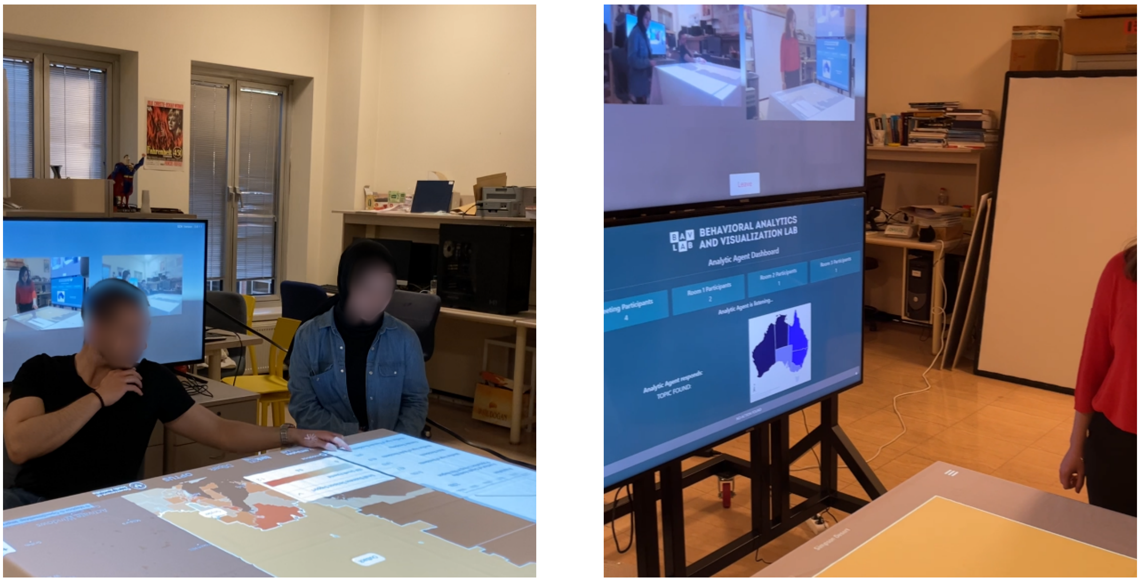


Figure 4.1 Photos from the demo study with the prototype XR system.

To test our prototype, we performed a demo study as users of the system (shown in Figure 4.1). The demo study highlighted that separating the synchronization logic from the shared view leads to synchronization problems between the different instances of this system. These problems arise primarily from the Kinect camera's inability to capture all user gestures, thereby hindering collaboration.

Due to the problems with the synchronization, this approach was abandoned in favor of the CA. However, the tabletop approach may be revisited in future studies, as the implementation of CA ensures synchronization between collaborators.

4.1.2 Pilot Study For Collaborative Atlas

Prior to finalizing our user study design, we conducted a pilot study with 12 participants using an earlier version of the CA. Our purpose was to identify any potential bugs in the CA's implementation and to uncover any flaws in our study design. A key difference between the finalized version of CA and the earlier version used in the pilot study is that, the earlier version included an additional feature where collaborators could toggle a second collaborative iframe on demand. This feature was developed to allow users to collaborate on multiple shared views.

However, during the pilot study, we observed that users did not tend to utilize this feature to collaborate on multiple views. Rather, they used this feature to perform tasks in parallel, independently of each other. Collaboration on a shared view was crucial for the integrity of our study, as the other conditions also relied on this collaborative approach. Although numerous prior studies have discussed the effectiveness of multiple workspaces [84; 55; 67], such a comparison was beyond the scope of this study. Therefore, the second iframe feature was removed from the CA to ensure it would not influence the results.

During the pilot study, we also observed that participants had faced difficulties using the AoO interface, particularly while using the comparison functionality. Despite receiving a briefing on the tool prior to the study, participants struggled with its usage. To strengthen participants' understanding of the tool and ensure a consistent level of understanding among all participants, we introduced a hands-on warm-up task into our study design.

4.2 Study Design

Our user study aims to investigate the effectiveness of groupware tools as a remote collaboration medium. For our user study, we designed a collaborative decision-making task that participants have to perform in pairs. To compare the effectiveness of groupware-based remote collaboration with videoconferencing-based remote collaboration, we conducted the user study in three conditions: on-site groups (serving as the control group), remote groups using a videoconferencing tool, and remote groups using groupware. In the study, the videoconferencing group used Zoom as a videoconferencing tool, while the groupware group used CA as the groupware.

The user study adopted a between-subjects design for its evaluation. Each pair was assigned to one of the conditions and instructed to perform the given task. Prior to the study, each participant was briefed about the AoO interface. In addition, participants in the groupware condition were given a detailed introduction to the CA tool. Each study session is recorded with Zoom for later analysis. Throughout the user studies, participants were physically monitored to assist them with any problems they might encounter.

4.2.1 Study Tasks

User studies include an initial warm-up task intended to familiarize the participants with the AoO interface and the main task of the study. In the warm-up task, participants are tasked with performing basic actions on the AoO interface, such as locating an SA2 region on the map, navigating to the details page of the region, retrieving and interpreting specific socio-economical statistics from the details page, and comparing multiple SA2 regions based on various socio-economic statistics. Following the warm-up task, participants proceed to the main task of the study. The main task was designed to simulate a real-world application of the AoO.

As discussed in Section 3.1, AoO is a GIS designed to support small business owners in planning more informed business strategies. By providing valuable socio-economic statistics about the SA2 regions within South Australia, the AoO assists small business owners in deciding on the optimal SA2 region to start or expand their businesses. Reflecting the real-world application of the AoO, the main task involves a scenario where participants assumed the role of small business owners. To complete the task, participants must decide on the most suitable region to start their businesses. Participants were presented with four SA2 regions and asked to decide on a region based on the specified socio-economic requirements.

Main Task Scenario: For the main task, participants assumed the role of a small business owner who wants to start a supermarket chain business. As the business strategy, supermarket chain must specifically target low-income customers. When deciding on a region, participants must consider the following requirements:

- The selected region should have a high percentage of lowest-quartile and second-quartile earners.
- The selected region should have a high average spent and count value on the business category "Retail Food Grocery and Supermarkets."
- The selected region should have a high relative business growth rate.

Considering these requirements, participants must decide on one of the given SA2 regions to start the supermarket chain business: *Mannum, Barossa-Angaston, Lyndoch,* or *Light*. Details of the task scenario alongside the warm-up task can be found in Appendix A.

The main task's regions and requirements were purposefully selected to direct participant decisions toward a particular region (See Figure 4.3). Although there was no definitive correct answer for the task, this approach aimed to encourage a consensus among participants' decisions. After completing the task, participants were asked to respond to a series of Likert-scale questions reflecting their individual experiences during the task.

4.2.2 User Study Conditions

User studies were conducted under three distinct conditions: on-site collaboration (C1), remote collaboration with a video conferencing tool (C2), and groupware-based remote collaboration (C3). Each pair was assigned to one of the conditions and performed the user study accordingly. Figure 4.2 provides an in-depth illustration of each condition.

In (C1), participants were located in the same place and used the same computer to conduct the user study. In this condition, one participant actively interacted with the AoO while the other participant assisted with the task completion. This condition simulates a traditional on-site collaboration where real-time interaction and communication between participants are unrestricted.

In (C2), participants were physically apart and relied on videoconferencing for remote collaboration. In this condition, one participant had direct access to the AoO interface (will be referred to as *driver*). To perform the study, both participants collaborated through Zoom, with the driver using screen sharing to display the AoO

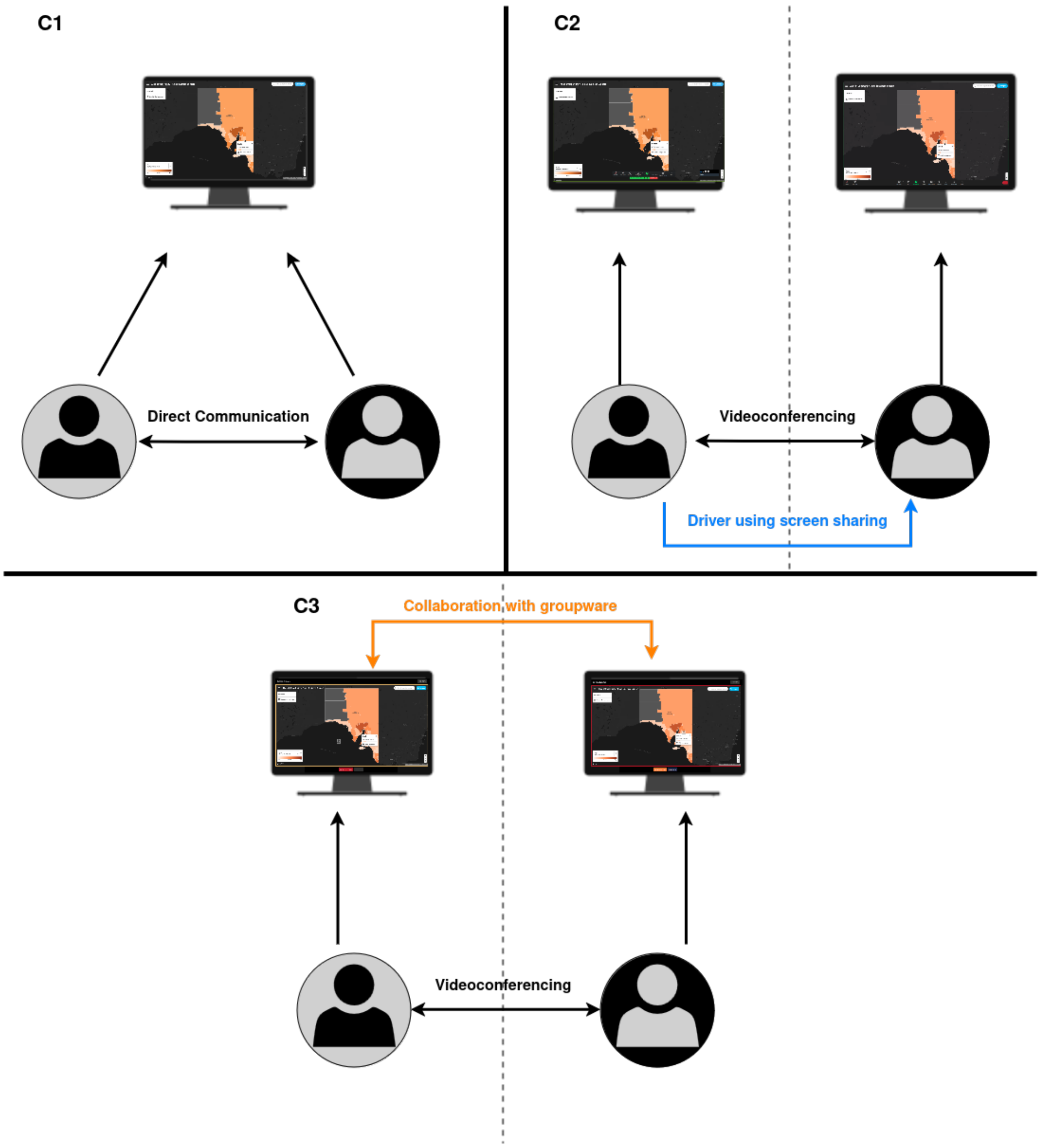


Figure 4.2 Illustration of user study conditions

interface to the other participant (will be referred to as *passenger*). This condition simulates a remote videoconferencing-based collaboration with limited real-time interaction and communication between participants.

In (C3), participants were also physically apart and used CA for remote collaboration. In this condition, the participants used videoconferencing for voice communication while using CA to interact with the shared AoO interface collaboratively. This condition simulates a remote collaboration where groupware tools are employed for a more interactive and dynamic remote collaboration experience compared to videoconferencing-based collaboration.

To define our evaluation metrics for the user study, we examined previous work on CSCW and collaborative decision-making. Assessment of the collaboration process presents unique challenges due to the significant resource requirements (i.e., time and participants) of such evaluative studies [5] and the need to measure multiple interdependent effects on various domains [6]. As a starting point, we visited the collaboration evaluation metrics outlined by Gutwin and Greenberg [45]. In their work, the authors outline the evaluation metrics as follows:

- **Effectiveness:** Determines whether the group's collaborative efforts lead to the desired outcome by examining the quality and correctness of the results.
- **Efficiency:** Evaluates the resources used during collaboration, such as time and effort, to determine how efficiently the group achieves its objectives.
- **Satisfaction:** Assesses group members' enjoyment and contentment with the collaborative process, indicating the overall satisfaction of the group activity.

Measuring the effectiveness of collaboration can be accomplished by analyzing the outcome of the collaboration. For our study, the outcome is an SA2 region selection. Although our user study task has no definite correct answer, as discussed in Section 4.2.1, given regions were purposefully selected to allow a ranking from most optimal to least optimal, which should lead to a consensus among the task responses. Methodologies that use consensus to evaluate the effectiveness of collaboration were employed in numerous prior work [22; 58].

For measuring the efficiency of collaboration, time-on-task has been widely utilized by the literature [6; 82]. This approach can easily utilized in our study by measuring the task completion times and comparing the results between the conditions.

One common method to measure user satisfaction is to employ user questionnaires. User questionnaires are heavily utilized in CSCW literature to evaluate the implemented groupware systems [82; 88]. Using questionnaires makes it possible to compare multiple conditions effectively and receive valuable feedback from the end-users. By employing post-task questionnaires after the main task, we can acquire valuable findings about user satisfaction.

Considering these metrics and the methodology in the prior work [6; 22; 58; 82; 88], we determined three evaluation metrics for this study:

- *Response consensus* representing effectiveness.
- *Time-on-task* representing efficiency.
- *User experience* representing satisfaction.

These metrics were chosen to evaluate the different collaboration conditions comprehensively. We then compared the different collaboration conditions with respect to those metrics to understand their impact on the collaboration.

To evaluate the consensus of responses within the group, we examined the selected SA2 region for each group and focused on the consistency of region selections within each condition. To measure time-on-task, the duration of each study session is recorded. To measure user experience, we employed post-task questionnaires after each study session.

4.3.1 Effectiveness

We analyzed the consistency of task responses across the pairs for each condition. This analysis is performed to determine whether different collaboration conditions influenced the participants' decision-making processes, which could result in reduced collaboration effectiveness. Since given SA2 regions and task requirements were deliberately selected to encourage a consensus among pair responses, the distribution of the task responses should be similar if the collaboration condition does not affect the decision-making process. Conversely, if there were notable differences in the distributions, it would indicate that the collaboration environment affects the decision-making process, possibly influencing the accuracy of the participants' decisions. To determine whether there are statistically significant differences in the pair responses, we categorized the task responses for each pair as either *Mannum* or *non-Mannum*. Subsequently, we conducted Fisher's exact test on a 2x2 contingency table with a significance level of 0.05 ($\alpha = .05$).

Figure 4.3 displays the socio-economic metrics of specified SA2 regions based on the task requirements. For each requirement, regions are rated on a scale from 1 (lowest) to 4 (highest), reflecting their relative ordering in the specified statistic. Based on our rating, given regions can be sorted from most optimal to least optimal like the following:

$$Mannum > Light > Lyndoch \geq Barossa\text{-}Angaston$$

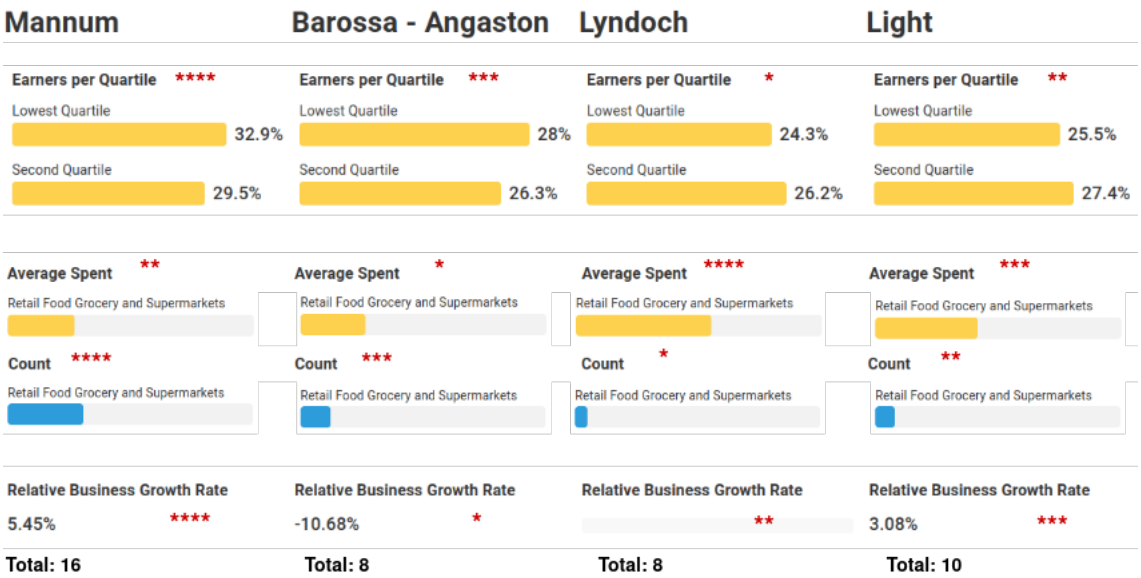


Figure 4.3 Required socio-economic statistics for the main task.

The missing relative business growth rate for Lyndoch is presumed to be zero. Although Lyndoch and Barossa-Angaston received equal ratings, Lyndoch is considered a better option due to having the highest average spent value and a non-negative business growth rate.

4.3.2 Efficiency

Task execution times were collected to compare collaboration conditions in terms of efficiency. An efficient collaboration should demand less time to complete the collaborative activity. Therefore, if task execution times are shorter for a specific condition, it can be inferred that this condition is more efficient. For each condition, we analyzed the task execution times of the pairs to determine whether there were statistically significant differences among the different collaboration conditions. For our statistical analysis, we performed a one-way ANOVA test with a significance level of 0.05 ($\alpha = .05$).

4.3.3 Satisfaction

To assess the user experience, we employed post-task questionnaires. Upon completing the study task, participants were asked to complete a six-question questionnaire designed to evaluate the user experience across six variables (see Table 4.1). While preparing the metrics, we were influenced by the Nasa-TLX [46] statements and the prior work [82]. We employed a Likert scale for response evaluation, with options ranging from 1 (Strongly Disagree) to 7 (Strongly Agree). These responses were analyzed using the Kruskal-Wallis H test ($\alpha = .05$) to determine if there were significant differences in the user experience across the various conditions.

Evaluation Variables	Statement
Workload*	The task was mentally demanding*
Stress*	I felt overwhelmed while performing the task*
Collaboration	I effectively collaborated with my group member
Performance	My performance met the expectations set for this task
Confidence	I felt confident while performing the task
Enjoyment	I enjoyed while performing the task

Table 4.1 Likert scale statements and evaluation variables.

Statements marked with an asterisk (*) indicate reverse-coded statements. For these statements, smaller values indicate higher satisfaction, whereas larger values represent higher satisfaction for the remaining statements.

5. RESULTS & DISCUSSION

The user study involved 60 university students (22 female and 38 male) who volunteered to participate. These participants were organized into groups of two, making up 30 pairs. These pairs were evenly distributed to three distinct setups (Figure 4.2), making 10 pairs for each condition. Each participant pair had known each other before the study.

This chapter discusses the user study results in detail. In Section 5.1, we discuss the pairs' task responses and their implications on the collaboration effectiveness. In Section 5.2, we investigate the task completion times for each condition. In Section 5.3, we report the post-task questionnaire results and elaborate on user experience. Finally, Section 5.4 offers an explanation of the results and explores potential relationships between collaboration effectiveness and user satisfaction.

5.1 Response Consensus

An analysis of the selected SA2 regions revealed a notable difference in the effectiveness of collaboration under various conditions. As illustrated in Figure 5.1, the response distributions for both on-site (C1) and groupware (C3) conditions displayed considerable uniformity, with both distributions skewed towards the most optimal SA2 region, *Mannum*. This implies that employing groupware for remote collaboration can achieve a level of effectiveness in decision-making processes that is comparable to on-site collaboration.

In contrast, the response distribution for the videoconferencing (C2) condition lacked such uniformity. Unlike the on-site and groupware conditions, where the majority of the pairs selected *Mannum* as the task response, the videoconferencing condition exhibited a much more scattered distribution of task responses. In this condition, fewer than half of the pairs selected the most optimal SA2 region as the task response. These results suggest that the use of videoconferencing for remote collaboration may hinder the decision-making process, resulting in less accurate decisions and a decrease in overall collaboration effectiveness.

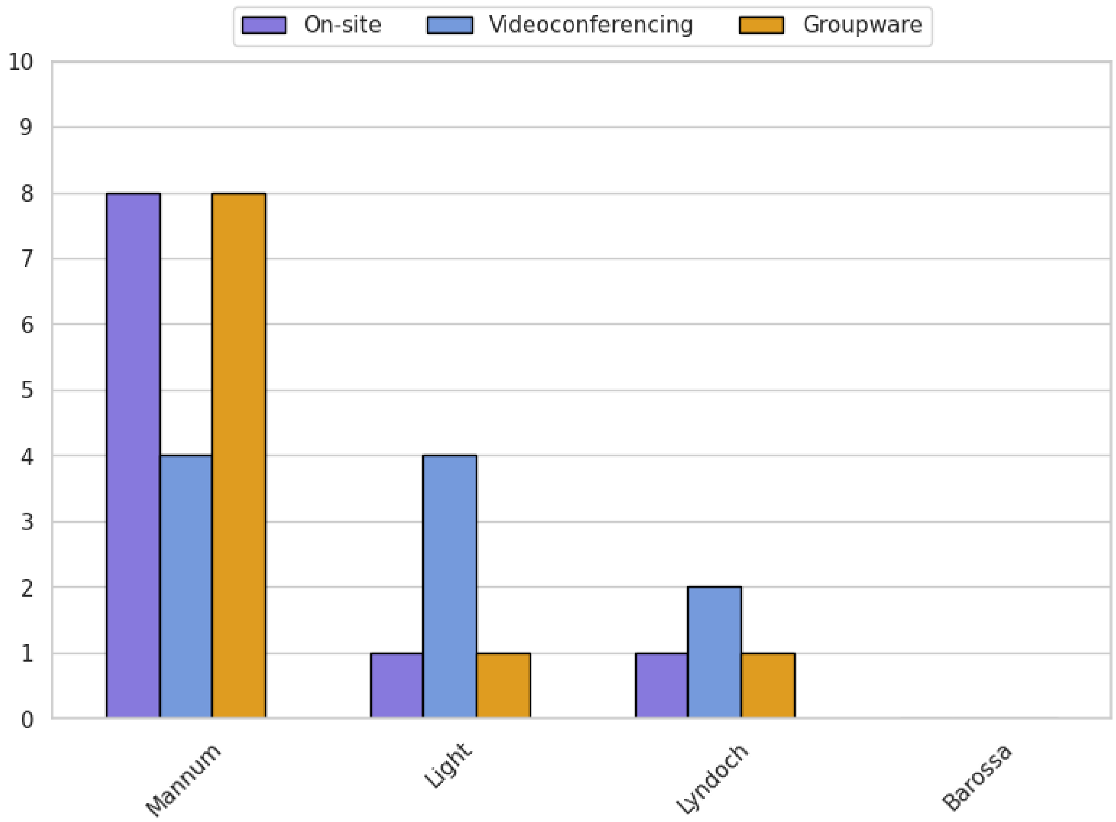


Figure 5.1 Distributions of the task responses for each collaboration condition.

Figure 5.1 illustrates the distribution of task responses. The x-axis represents the specified SA2 regions, sorted from most optimal to least optimal, while the y-axis represents the number of responses for each collaboration condition. Our findings indicate that remote collaboration using groupware leads to higher collaboration effectiveness compared to remote collaboration via videoconferencing.

To explain this notable difference between the videoconferencing and the groupware conditions, we investigated each study session in detail. Our analysis revealed that in both the on-site (C1) and groupware (C3) conditions, participants frequently pointed out elements on the screen using either their hands (in C1) or avatars (in C3). However, in the videoconferencing condition (C2), participants were unable to use gestures to indicate elements, as Zoom did not support avatars during the time of the study. Instead, participants verbally described the elements when they were interested in them, which may have introduced errors to the decision-making process and resulted in increased mental workload for the collaborators.

In addition to the absence of pointing gestures, our analysis of the study sessions revealed another behavioral difference among participants across the collaboration conditions, possibly originating from the lack of pointing gestures in the videoconferencing condition (C2). We observed that in C2, the *passenger* participants oftentimes lost their focus during the study. Instead of focusing solely on the study task, these participants engaged in additional activities, such as interacting with their surroundings or checking their phones when not actively interacting with the interface. We hypothesize that passenger participants are prone to multitasking during videoconferencing, leading to increased stress and fatigue, as discussed in the literature [79; 76; 65]. Consequently, we argue that the increased stress and fatigue may negatively affect participants' decision-making processes and lead them to faulty decisions.

Although these results show a noticeable difference in response distributions, claiming a significant difference among the collaboration conditions without conducting statistical tests is not feasible. For the statistical analysis of categorical data, such as in this thesis, a commonly employed method is the chi-square goodness of fit test [15]. However, the goodness of fit test presumes at least five expected observations per group, a condition that was not met in this study.

As an alternative approach, we compared the distributions of C2 and C3 among each other since C1 and C3 had identical distributions. This comparison was performed using Fisher's exact test ($\alpha = .05$) on a 2x2 contingency table. To align our results with the 2x2 contingency table format, we reformatted the task responses as *Mannum* and *non-Mannum*. After reformatting, we obtained the following contingency table:

	Mannum	Non-Mannum	Total
Videoconferencing (C2)	4	6	10
Groupware (C3)	8	2	10
Total	12	8	20

Table 5.1 2x2 contingency table of task responses

Fisher's exact test yielded a p-value of 0.16, indicating that the difference between C2 and C3 is not statistically significant. Despite the absence of a statistically significant difference between the remote conditions, it is important to note that these conditions exhibited noticeable differences throughout the user studies and in our observed results.

5.2 Time-on-task

The preliminary analysis of task completion times highlighted a noteworthy difference in the *efficiency* of collaboration between the on-site (C1) condition and the remote conditions (C2, C3). As shown in Table 5.2, participants in the on-site condition completed the study task in considerably less time than their remote counterparts. A one-way ANOVA analysis revealed a significant difference in task completion times across the conditions ($f(2,27) = 4.58$, p-value = 0.01). Post-hoc pairwise comparisons, using Tukey's HSD tests, highlighted that task completion times for the remote conditions were significantly longer than for the on-site condition (videoconferencing: p-value = 0.04; groupware-based: p-value = 0.03). Contrarily, the post-hoc analysis found no significant difference in task completion times among the remote conditions (p-value = 0.98).

			Post-hoc Comparisons (p-value)		
	Mean (mm:ss)	SD (mm:ss)	C1	C2	C3
On-site (C1)	4:11	1:07	1.000	**0.030****	**0.045****
Videoconferencing (C2)	5:46	1:27		1.000	0.982
Groupware (C3)	5:40	1:20			1.000

Table 5.2 Detailed statistics of the task completion times

These results highlight that on-site conditions offer significantly more efficient collaboration than remote conditions. To understand the underlying reasons for this observed difference, we will revisit the study sessions, particularly focusing on how users interacted with the AoO interface.

Our analysis of user interactions revealed a similar interaction pattern across remote conditions. In the remote conditions, pairs tend to form a *driver-passenger* pattern while performing the tasks, with the passenger user reading the task requirements to the driver user and the driver interacting with the element of interest depending on the requirement. Although this pattern was anticipated for C2, it was unexpected to observe it so frequently in C3, given our implementation of the lock exchange system. Regardless, what we observed is that collaborators rarely exchanged controls while conducting the tasks in C3. As a result, the remote conditions exhibit a remarkable similarity in how participants interacted with the interface.

A similar driver-passenger pattern was also observed in the on-site condition. In C1, while the driver user interacted with the AoO interface, the passenger read the task requirements to the driver using their dedicated device for the user study. However, in this condition, the driver user could also view the passenger's dedicated device; therefore, it can also view the task requirements itself. Hence, the driver does not necessarily need the passenger to specify the task requirements, which reduces the time spent on verbal communication between the collaborators. We hypothesize that this reduction in verbal communication time can be linked to the difference in task completion times between the on-site and remote conditions.

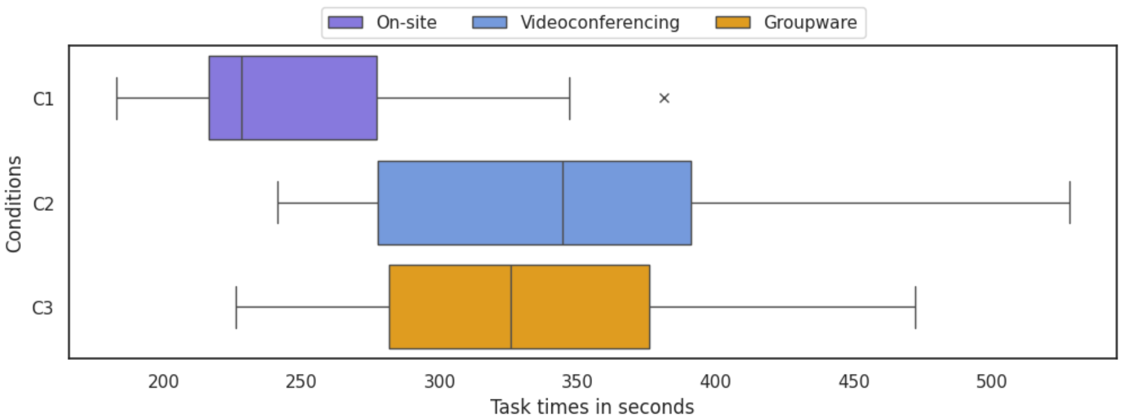


Figure 5.2 Distributions of the task completion times for each collaboration condition.

As illustrated in Figure 5.2, remote conditions exhibit similar distributions, with groupware (C3) having relatively shorter task completion times when compared to videoconferencing (C2). Although we could not specify that C3 offers significantly more efficient collaboration than C2, we can conclude that C3 offers higher collaboration effectiveness without resulting in a trade-off with collaboration efficiency.

5.3 User Experience

Figure 5.3 displays the post-task questionnaire results for each evaluation metric discussed in Section 4.3.3. For *Workload* and *Stress*, lower values are preferable, while larger values are preferable for the remaining metrics. The medians of each metric are shown with a red line. The results of the post-task questionnaires indicate that the groupware condition (C3) offers an overall higher user experience than both on-site (C1) and videoconferencing (C2) conditions. For the evaluation metrics

Collaboration and *Performance*, C1 and C3 received equivalent user ratings, with both conditions receiving slightly higher ratings than C2. For the remaining metrics, C3 clearly received higher ratings than C1 and C2.

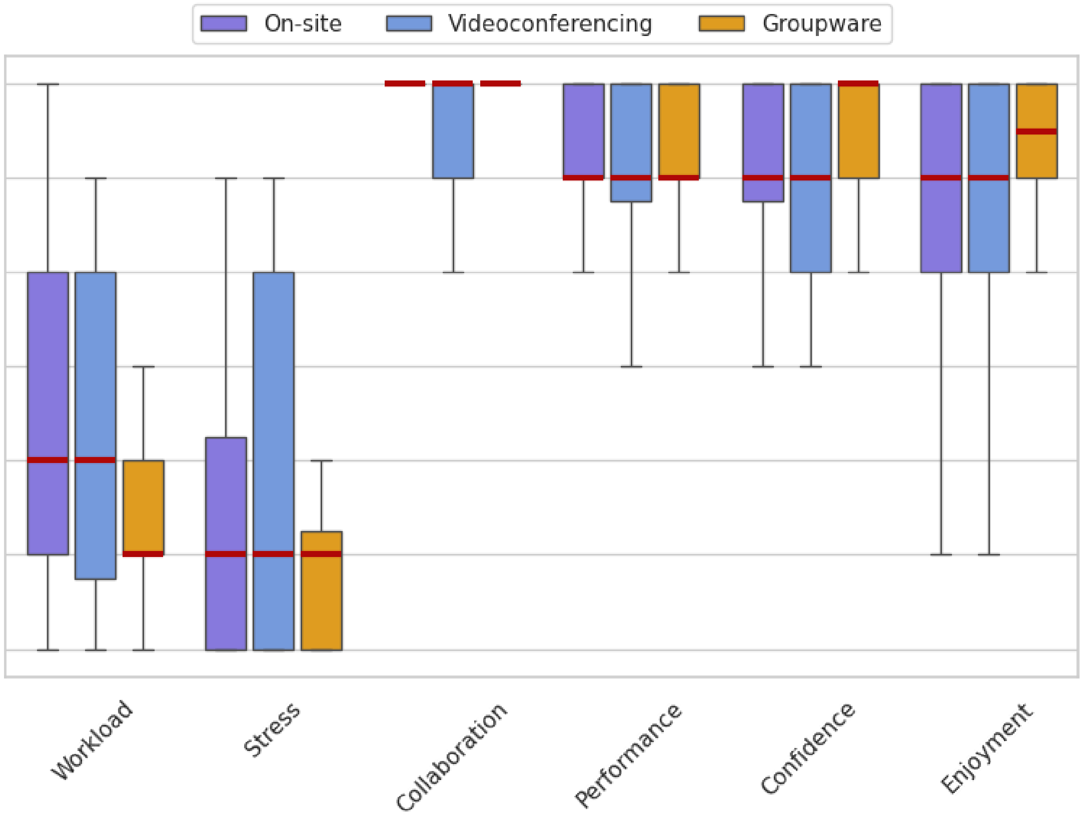


Figure 5.3 Post-task questionnaire results, ranging from 1 (Strongly Disagree) to 7 (Strongly Agree).

The **Workload** evaluates the extent of mental effort participants wielded during the study task. Lower ratings correspond to a minimal mental workload, whereas higher ratings correspond to a significant mental workload. For this metric, questionnaire results were rather unexpected, with C1 and C2 having higher median values than C3. These results suggest that participants experienced a greater mental workload in both C1 and C2 relative to C3 during the study sessions. While a higher mental workload in C2 was anticipated due to the absence of pointing gestures (refer to Section 5.1), the increased workload observed in C1 was rather unexpected. This outcome suggests that pointing gestures do not necessarily reduce the mental workload within the context of this thesis.

To understand the reasons behind the observed workload results, we investigated questionnaire answers based on the pairs' task responses. Specifically, we aimed to determine whether perceived workload affected the selection of regions in the study task. If participants who selected Mannum reported substantially lower workload ratings compared to those who did not select Mannum, it would support the hypothesis that higher workload correlates with less accurate decision-making. Our investigation revealed that the median workload rating for participants who chose Mannum was 1.5 points lower than for those who did not (Mannum median: 2, non-Mannum median: 3.5). This result indicated that pairs who experienced lower workload tend to make more accurate decisions in our task.

The **Stress** evaluates the level of stress participants experienced during the task. Lower ratings indicate minimal stress, whereas higher ratings indicate increased stress. The questionnaire results for this metric exhibited uniformity in the median values across conditions, with variations on the rating distributions favoring the C3. These findings imply that participants experienced less stress while performing the task in C3 compared to C1 and C2. Considering that C3 also resulted in a lesser workload than C1 and C2, it is reasonable to associate lower stress with C3 since workload and stress are often interrelated [76; 78].

In **Collaboration**, participants rated their collaboration experience with their group members. The questionnaire results indicate a uniformity among the condition's medians, with C2 being rated slightly lower than C1 and C3. Notably, nearly 75% of participants responded with *7 (Strongly Agree)* to the statement assessing collaboration, while the remaining ratings were distributed between 5 and 6 points. This response distribution indicated that participants experienced similar levels of collaboration during the task, regardless of the assigned condition. This indicates that, despite the variations observed in other metrics discussed earlier, these differences did not influence the participants' perceived collaboration experience.

In **Performance**, participants rated their perceived performance during the study session based on how successfully they believed they performed the task. Ideally, the results of this metric should align with the collaboration effectiveness, as participants are indirectly evaluating the accuracy of their responses. However, the questionnaire results do not indicate a clear separation among the conditions for this metric.

Since the results for the performance metric were rather unexpected, we conducted a detailed analysis of the questionnaire answers based on the pairs' task responses. Our analysis demonstrated that the median performance rating for participants who selected Mannum was 1 point higher than for those who did not (Mannum median: 7, non-Mannum median: 6). This result indicates that although collaboration conditions did not exhibit noticeable differences in the performance metric, pairs who selected the most optimal region tended to rate their performance higher than those who did not.

	Median (C1/C2/C3)	SD (C1/C2/C3)	Sum (C1/C2/C3)	Min-Max (C1/C2/C3)	P-value
Workload	3.0/3.0/2.0	1.79/1.86/1.35	69/66/50	1-7/1-6/1-7	0.20
Stress	2.0/2.0/2.0	1.73/1.79/1.41	50/56/40	1-7/1-6/1-7	0.38
Collaboration	7.0/7.0/7.0	0.41/0.60/0.52	136/131/136	6-7/5-7/5-7	0.17
Performance	6.0/6.0/6.0	0.89/0.93/0.80	124/123/126	4-7/4-7/4-7	0.90
Confidence	6.0/6.0/7.0	0.99/0.94/0.75	121/121/128	4-7/4-7/5-7	0.42
Enjoyment	6.0/6.0/6.5	1.53/1.30/0.80	113/114/126	2-7/2-7/5-7	0.29

Table 5.3 Descriptive statistics and p-values of the post-task questionnaire results for each condition.

The **Confidence** assesses how confident participants were during the user study. This metric is used to evaluate how confidently participants decided on an SA2 region in the task. The questionnaire results for this metric notably favored C3, which exhibited higher median values compared to C1 and C2. In contrast, C1 and C2 received similar ratings with equivalent median and sum values. These results indicate that in C3, participants were more confident with their answers. Considering that participants in C3 experienced a lesser workload, it is reasonable to attribute these higher confidence ratings to the lower perceived workload.

The **Enjoyment** evaluates the level of enjoyment participants experienced during the task. The ratings for this metric also showed a notable preference towards C3, characterized by a higher median value and a lower deviation from the median. Similar to the confidence metric, C1 and C2 demonstrated equivalent ratings with equal median and sum values. These results imply that participants in C3 experienced greater enjoyment while performing the study task. As discussed in performance and confidence metrics, higher enjoyment can be linked to the reduced workload participants experienced in the C3.

The overall questionnaire results demonstrate a preference for C3, with noticeable differences when compared to both C1 and C2. Median values were equal between C1 and C2, exhibiting only minor differences in their deviations. A Kruskal-Wallis H test was performed to determine whether the differences between C1-2 and C3 were statistically significant. Contrary to our observations, the test did not identify any significant differences between the conditions, with the lowest p-values observed on *Workload* (p-value: 0.20) and *Collaboration* (p-value: 0.17) metrics. This suggests that the variations in collaboration conditions examined in this study do not significantly impact collaboration satisfaction. Descriptive statistics and calculated p-values for each metric are displayed in Table 5.3.

The results indicate notable differences among collaboration conditions, particularly in collaboration effectiveness and efficiency. According to the task responses, on-site (C1) and groupware (C3) conditions achieved higher levels of collaboration effectiveness compared to videoconferencing (C2). A one-way ANOVA of task completion times demonstrated a statistically significant difference in collaboration efficiency between on-site and remote conditions, with remote conditions showing comparable task completion times. Regarding collaboration satisfaction, the post-task questionnaires suggest that the groupware condition provided the highest user experience, followed by on-site and videoconferencing conditions. Table 5.4 provides a detailed summary of the study's findings for each condition.

Metric	Condition Order
Effectiveness	$C1 \approx C3 > C2$
Efficiency	$C1 > C3 \approx C2$
Satisfaction	$C3 > C1 > C2$

Table 5.4 Overview of user study results

As illustrated in Table 5.4, groupware clearly outperformed videoconferencing in collaboration effectiveness and satisfaction while demonstrating comparable performance in collaboration efficiency. These results underscore the potential of groupware as an alternative medium for remote collaboration.

As discussed in Sections 5.1 and 5.3, the differences between the C2 and C3 can be attributed to the increased workload participants experienced in the videoconferencing condition. Our observations suggest that this increase in the workload could be linked to the following factors:

- Absence of pointing gestures during videoconferencing
- Tendency to multitasking for passenger users as they do not necessarily need to interact with the interface continuously.

The observed problems are aligned with the root causes of Zoom Fatigue, as identified by Riedl [78] and outlined in Table 2.1. The absence of pointing gestures can be associated with the lack of non-verbal cues, whereas the videoconferencing condition clearly demonstrates the negative effects of multitasking on remote collaboration.

These findings strongly support Riedl's definitions of the underlying causes of Zoom fatigue.

To verify our finding that the increased workload in videoconferencing negatively impacts collaboration effectiveness, we conducted a comparative analysis of task responses under remote conditions with respect to the perceived workload. In our analysis, we assessed each pair's workload, which was calculated as the average of both participants' ratings and their selected SA2 region. These values were then clustered into three groups using K-means clustering [64]. If our finding holds, the clusters should exhibit a distinct separation based on the collaboration condition, questionnaire ratings, and the selected SA2 region. Figure 5.4 illustrates the clustering results concerning the pairs' workload ratings and their selected SA2 region.

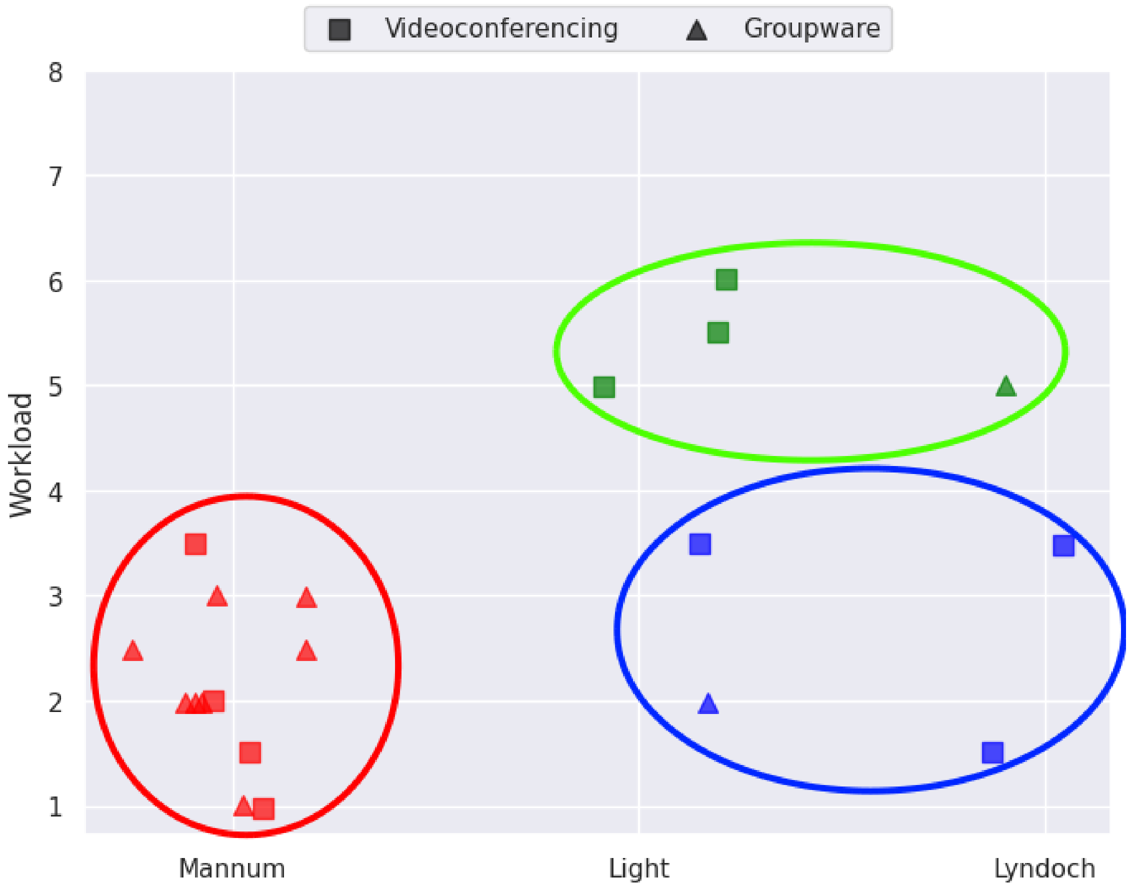


Figure 5.4 Workload ratings for each pair grouped by task responses.

In Figure 5.4, each point represents a pair, with the x-axis showing the region selected by the pair and the y-axis displaying the average workload score based on the post-task questionnaire. The figure illustrates three distinct clusters. The first cluster (shown in *red*) consists of pairs reporting lower workload ratings and selecting the task's most optimal region. In contrast, the second (shown in *green*) and the third (shown in *blue*) clusters consist of pairs reporting mostly higher workload ratings and choosing other available options. These clusters demonstrate a clear separation among the selected SA2 regions based on the perceived workload. Notably, the first cluster predominantly includes pairs that performed the study using groupware (C3), whereas the second and the third clusters mainly consist of pairs that conducted the study via videoconferencing (C2).

The notable difference between the clusters supported our finding that the increased workload experienced in videoconferencing negatively influenced the accuracy of the pairs' decisions, thereby lowering collaboration effectiveness.

We extended this analysis to the remaining metrics in the questionnaire to determine if similar clustering patterns emerged. In addition to workload, comparable clustering patterns were observed for the *Stress* (Figure 5.5), *Confidence* (Figure 5.6), and *Enjoyment* (Figure 5.7) metrics. These findings suggest a potential correlation with the workload ratings.

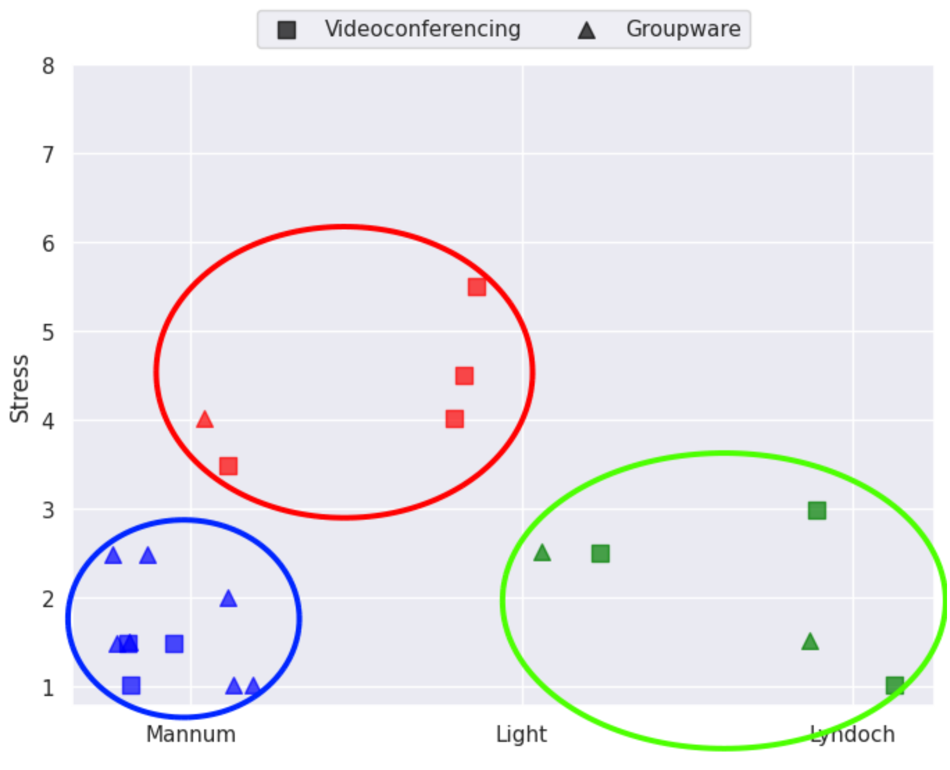


Figure 5.5 Stress ratings for each pair grouped by task responses.

In contrast to the differences observed among the remote conditions, the on-site condition did not exhibit such clustering patterns in user experience ratings (see Figure 5.8). While participants' ratings for user experience were lower compared to the groupware condition, the on-site condition demonstrated equivalent collaboration effectiveness to groupware, according to our results. We hypothesize that these outcomes might be related to the differences between on-site and remote collaboration. However, a detailed examination of the differences between on-site and remote collaboration falls outside the scope of this study and will not be examined in this thesis.

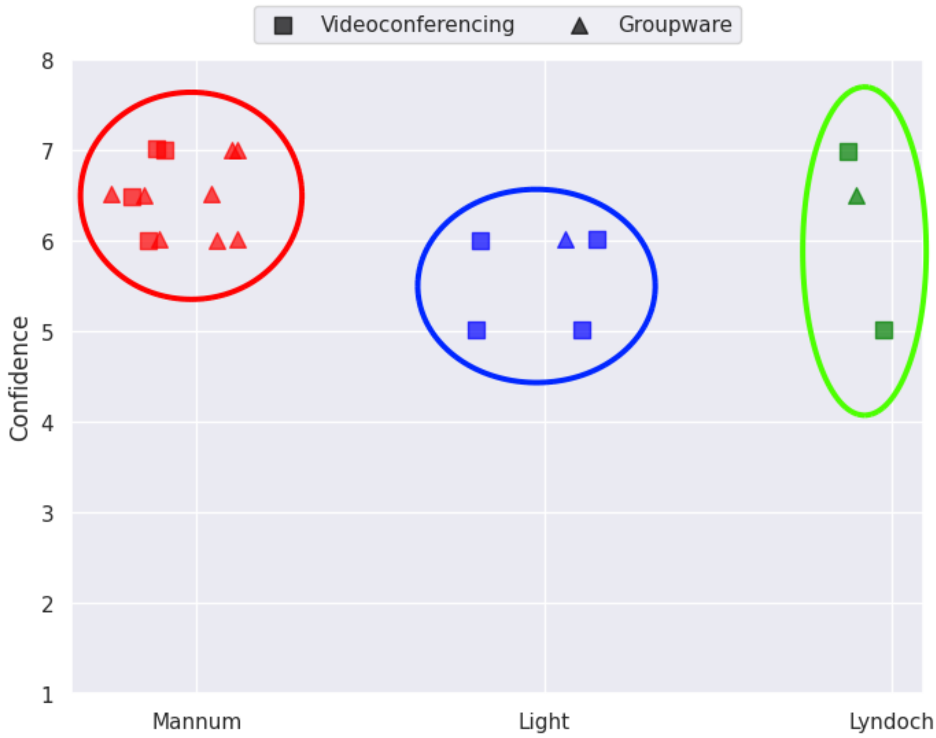


Figure 5.6 Confidence ratings for each pair grouped by task responses.

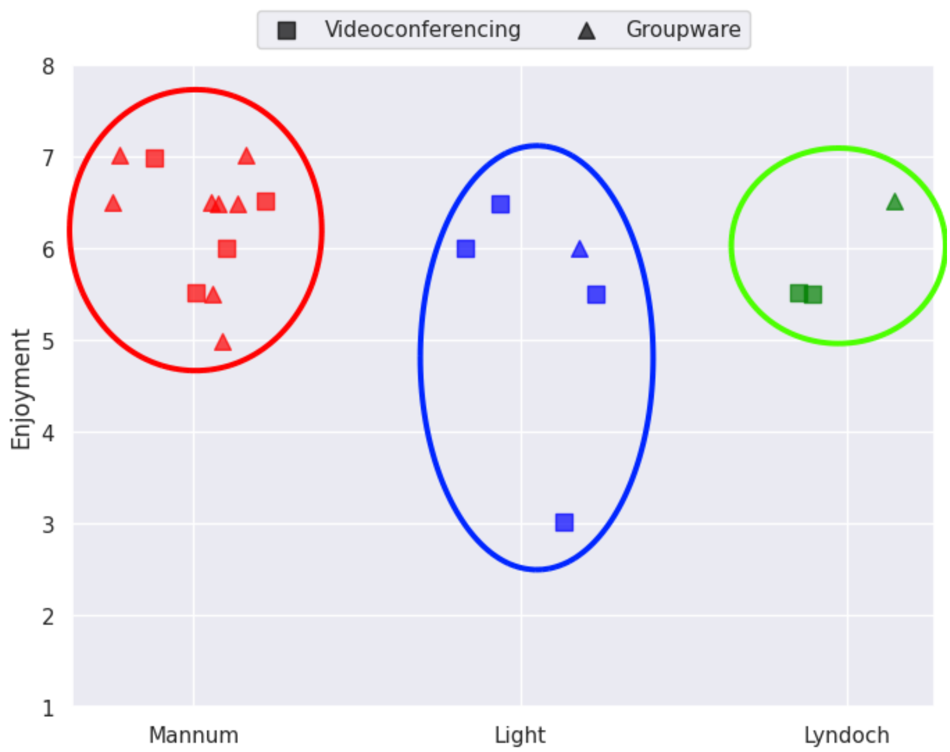


Figure 5.7 Enjoyment ratings for each pair grouped by task responses.

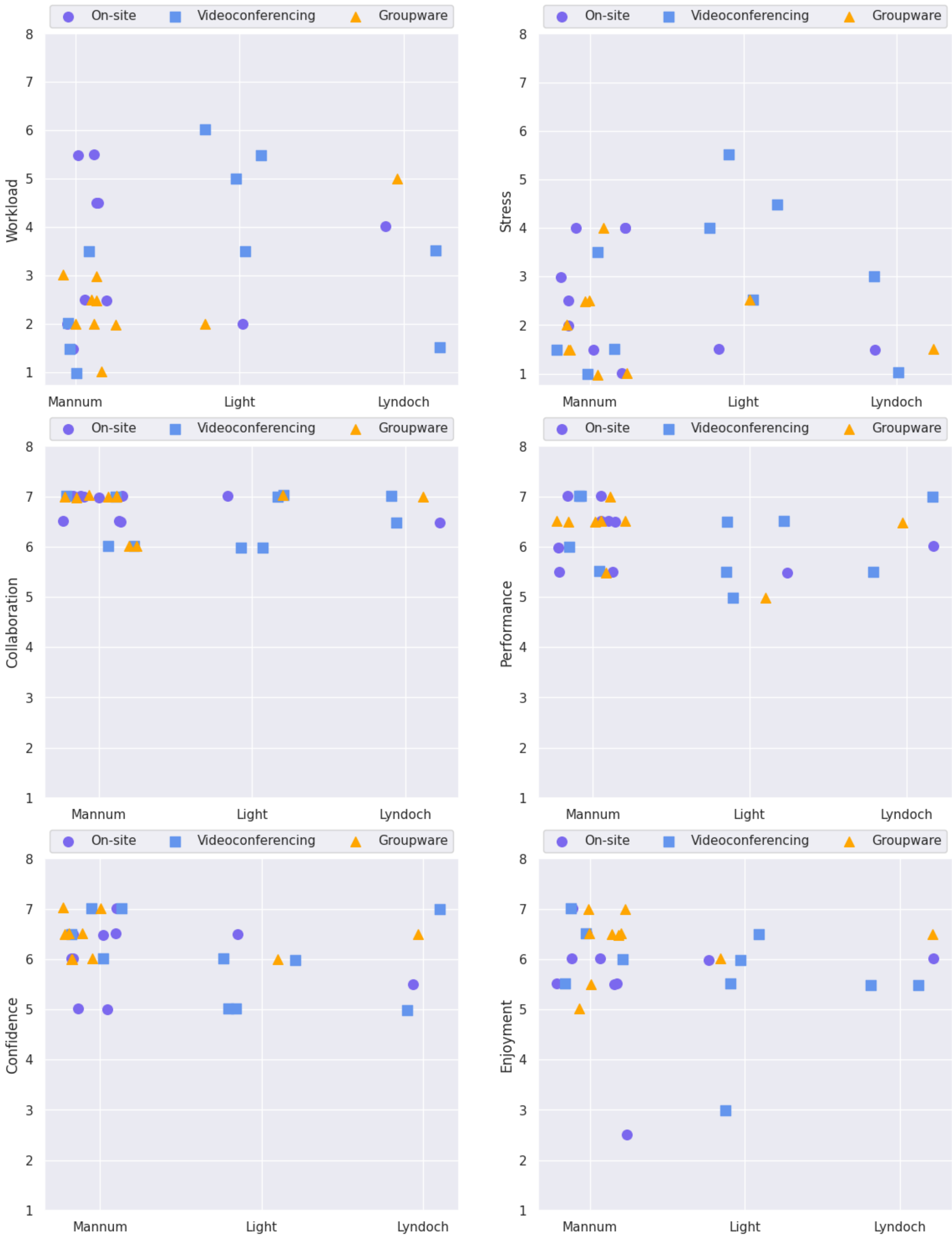


Figure 5.8 Ratings for each pair grouped by task responses with the on-site condition.

6. LIMITATIONS & FUTURE WORK

This thesis possesses several limitations that suggest directions for future work. One major limitation was the number of participants involved. Although 20 participants were recruited for each condition in the user study, these participants were organized into pairs, making ten observations for each condition. Furthermore, our study design only evaluated collaboration with groups of two. However, in practical scenarios, collaboration often includes more than two collaborators. Numerous studies have demonstrated that the size of a group significantly influences both group performance and satisfaction [28; 40; 3], with larger groups frequently exhibiting superior performance compared to smaller groups when utilizing groupware [28; 40; 3; 27; 86; 87]. Unfortunately, this thesis could not investigate collaborative processes within larger groups due to the limited number of participants.

Another limitation of this study was presented in the user study task. This research solely focused on employing groupware for geographic data visualization. However, both videoconferencing and groupware tools are also extensively utilized in biology [82; 88] and programming [42; 37] domains. Investigating the collaborative processes within these varied domains could yield additional insights into the potential of groupware as a medium for remote collaboration. Nonetheless, given that we only had a GIS as an underlying interface, we had no opportunity to explore the collaboration experience for the domains other than geoinformation.

In future studies, we propose two improvements to Collaborative Atlas (CA). For the first improvement, as discussed in Section 3.2.3, we suggest implementing a concurrency control mechanism without a global lock mechanism. During the user studies, we observed that participants in the groupware condition (C3) exhibited slightly less collaborative engagement when they did not possess the lock. Although this effect was not as prominent as what we observed among the passenger users in videoconferencing, it still encouraged minor multitasking for the participants without the lock. This may have influenced the results for C3, thus obscuring the full potential of groupware.

For the second improvement, we aim to revisit the immersive collaboration approach by using CA. As discussed in Section 4.1.1, the immersive approach was abandoned due to the limitations of the event synchronization. However, since CA ensures a shared view among the collaborators, it addresses this limitation and opens up the way for new studies using immersive reality technologies.

7. CONCLUSION

This thesis investigates the potential of groupware as a medium for remote collaboration. Specifically, this study aims to determine whether utilizing groupware for remote collaboration, typically conducted through videoconferencing and screen-sharing, results in a superior collaboration experience compared to videoconferencing.

For our investigation, we conducted a comparative user study under three collaboration conditions: on-site (C1), videoconferencing (C2), and groupware (C3). The outcomes were then compared for each condition based on three specified metrics: *Effectiveness*, *Efficiency*, and *Satisfaction*.

In conclusion, our user study with 60 university students provided valuable insights into the dynamics of remote collaboration using groupware. According to the study results, groupware clearly outperformed videoconferencing in collaboration effectiveness and satisfaction while exhibiting slightly better collaboration efficiency.

According to the task responses, groupware demonstrated equivalent collaboration effectiveness to the on-site condition. The distribution of task responses showed uniformity for both conditions, with participants predominantly selecting the most optimal answers. Conversely, such uniformity was absent in the videoconferencing condition, where responses were scattered across various options. This divergence in the videoconferencing condition indicates a reduction in collaboration effectiveness, which may affect participants' decision-making processes and potentially lead them to make faulty decisions.

Furthermore, a detailed analysis of task execution times revealed differences in collaboration efficiency. The on-site condition exhibited significantly shorter task completion times compared to the remote conditions, indicating a higher collaboration efficiency. Conversely, no significant differences were observed between the remote conditions, with task completion times being comparable. Notably, groupware demonstrated slightly shorter task completion times than videoconferencing. These results underscore that both videoconferencing and groupware exhibit equivalent collaboration efficiency, with groupware performing slightly better.

Finally, the analysis of the post-task questionnaire results suggests a general preference for the groupware condition. According to the results of the questionnaire, groupware received the highest user ratings, followed by on-site and videoconferencing conditions. Although there were no statistically significant differences among the conditions, user experience ratings favored groupware, which indicated higher collaboration satisfaction.

These findings underscore the potential of groupware as an effective medium for remote collaboration. Despite the limitations discussed in Chapter 6, groupware offered a collaboration experience comparable to that of on-site collaboration. We believe our results can encourage the greater adoption of groupware for remote collaboration while also providing valuable insights for developers of such applications.

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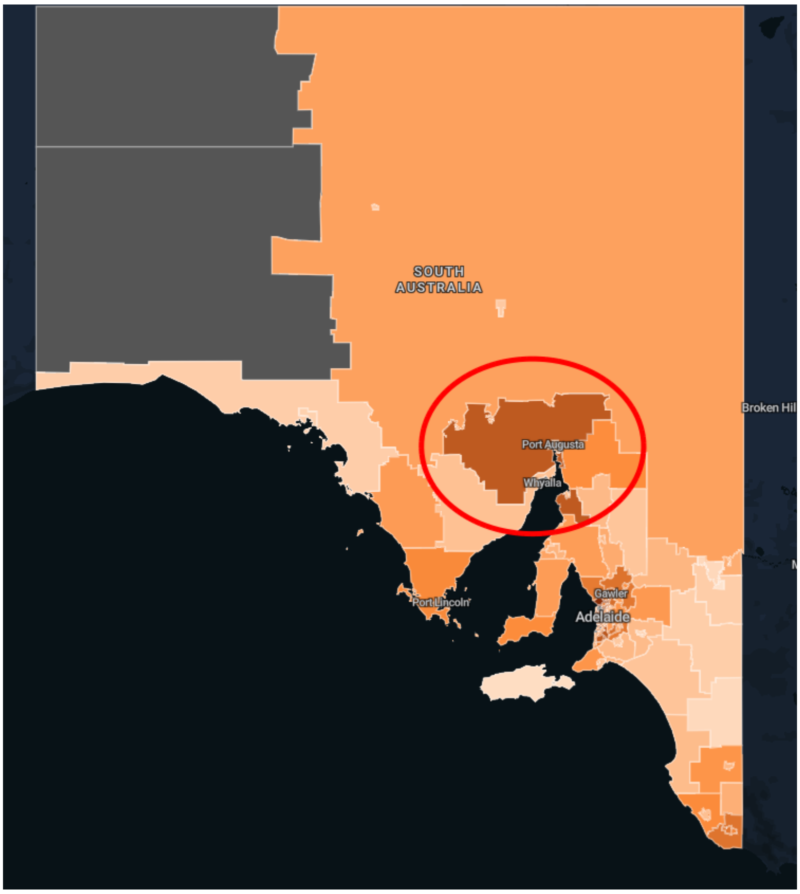
APPENDIX A

Warm-up Task

This task aims to familiarize you with the AoO interface.

Please find and navigate to the **Quorn - Lake Gilles** region (highlighted with the red circle).



The following questions will be answered according to the Quorn - Lake Gilles region.

1.1 What is the Median age of the male population in the region?

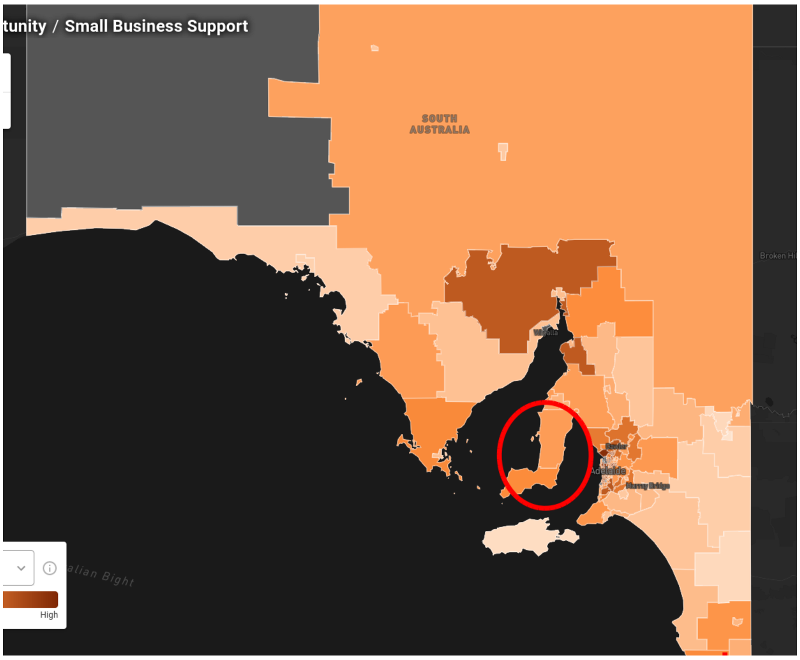
1.2 What is the Relative Business Growth Rate of the region?

1.3 What is the percentage of top %1 income sharers in the region?

1.4 Compare the weekly rent prices of 3BR apartments and 3BR houses in the region. Which one of them is more expensive?

1.5 Which business category has the highest average spent value?

Now, go back to the map and find the **Yorke Peninsula - North** and **Yorke Peninsula - South** regions highlighted in red. Add those two regions to the comparison and answer the following questions according to it.



2.1 Which one of the regions has a higher population?
___ North   ___ South

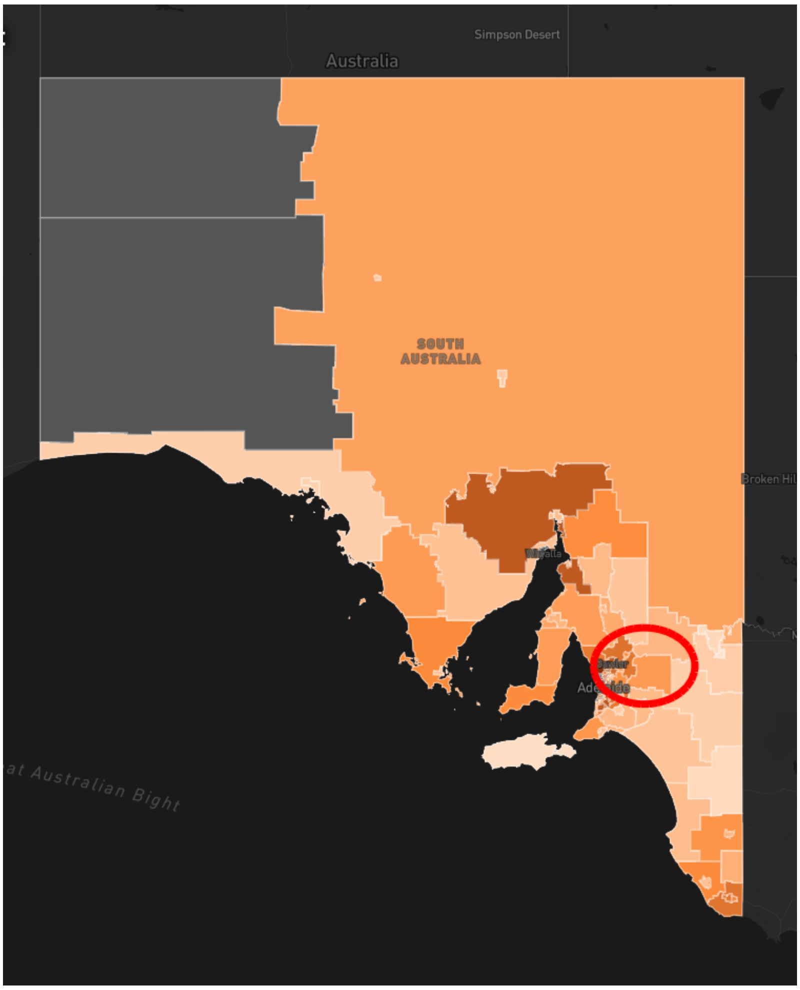
2.2 Which one of the regions has a higher mean income amount?
___ North   ___ South

2.3 Which region has a higher number of Construction businesses?
___ North   ___ South

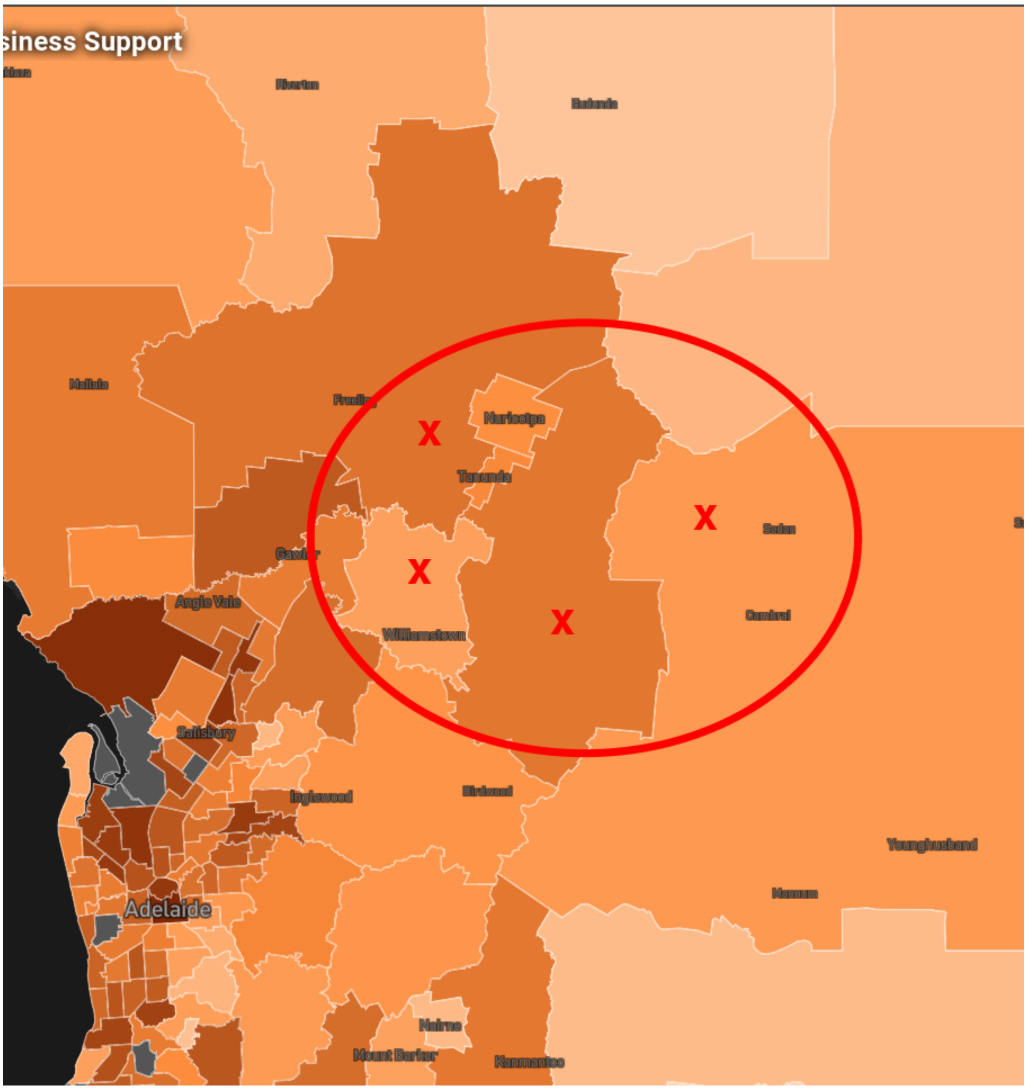
User Study Main Task

In this task, you will try to find the optimal region to start your business by using the data in the Atlas and explanations given below.

Please locate the following regions on the circled region of the map: **Mannum - Barossa - Lyndoch - Light**.



Regions marked with the **X** in the map are **Light**, **Lyndoch**, **Barossa**, and **Mannum** (from left to right). Please add these regions to the comparison.



You are a business owner who will start a supermarket chain business in one of the highlighted regions above. This supermarket chain will target low-income people who want to access their basic needs. To choose which region to start this business, you will consider three parameters:

- High percentage of lowest quartile and second quartile earners (economy).
- High average spent and count value (financial transactions) on "Retail Food Grocery and Supermarkets."
- High relative business growth rate (growth).

Which SA2 region would you choose to start your business?

___ Mannum
___ Barossa - Angaston
___ Lyndoch
___ Light