Evaluating Information Synchronization Methods in Large Display-Centered Multi-Device Collaboration

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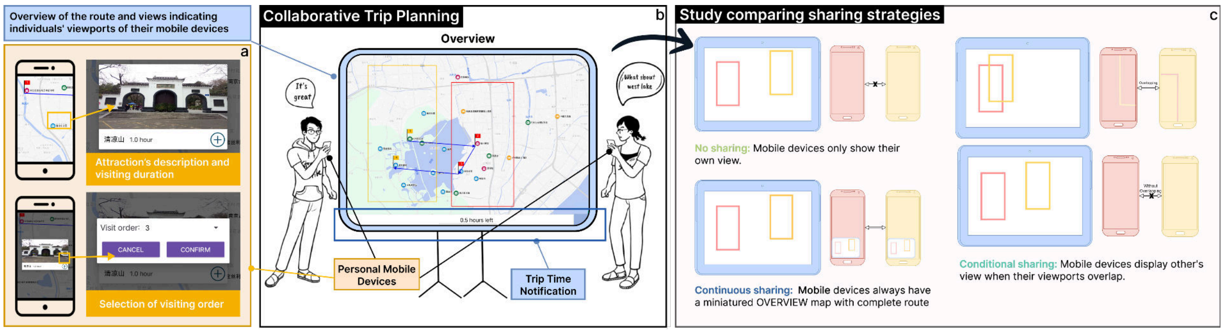

Figure 1: Through co-located collaborative trip planning experiments (a, b), we investigated the impact of different information synchronization methods (c) in a large display-centered multi-device environment (b).

Abstract

Information-sharing between devices is believed to affect collaboration efficiency and user experience in multi-device environments. However, existing research has not adequately explored how different information-sharing methods impact users in common multi-device setups involving both large and small devices. To address this gap, our study investigates the impact of three different information sharing methods-**No Sharing**, **Conditional Sharing**, and **Continuous Sharing**—on user collaboration behavior, task completion time, and user experience in a multi-device environment. We also examined the role of participant familiarity and its effect on collaboration. We conducted a within-subject experiment in which participants collaboratively planned a shared trip using three different information-sharing modes. We found that different information-sharing modes did not significantly change users' task efficiency and exploration habits, as participants often focused on the same region regardless of the mode. Familiarity between users significantly affected both communication time and frequency. Participants generally preferred the continuous information-sharing mode. These findings suggest that incorporating continuous information-sharing features can improve user satisfaction. Designers should also consider user familiarity to create adaptive communication features that enhance collaboration efficiency and user experience.

Index Terms: Collaborative Visualization, Large Display Visualization, Multi-Device Visualization

1 Introduction

The advancement of wireless communication technologies (e.g., Bluetooth, Wi-Fi, and NFC) and improvements in computational capabilities (e.g., more powerful processors and greater storage in mobile and stationary devices) have significantly contributed to the growing prevalence of multi-device environments. These technologies enable seamless connectivity and real-time data transfer, allowing users to interact with multiple devices in a synchronized manner. As a result, smartphones, tablets, and large displays can now be easily integrated into a unified system, facilitating new forms of interaction and collaboration. Such interconnected environments have been shown to enhance team communication, streamline cooperative work, and facilitate decision-making and sensemaking processes [14, 2, 5, 18]. This trend highlights the potential for these technologies to transform how people work and interact across multiple devices, providing a more integrated and effective user experience.

In multi-device collaborative environments, different types of devices often serve distinct purposes, driven by their respective physical attributes and affordances. Broadly, these devices can be categorized into two groups: large, stationary displays, and small, portable devices. The unique characteristics of these devices influence their respective roles within multi-device environments. Large displays typically act as shared, public resources used for presenting information that is beneficial to the entire group. They provide an overview, often facilitating collaborative sensemaking by making information accessible to all participants. Conversely, smaller mobile devices serve as personal tools, allowing individual users to explore specific details of the information independently [20, 16]. This separation of roles ensures that both shared collaborative efforts and personal exploration are supported effectively, creating an environment where global awareness and individual focus are well balanced.

Effective information sharing between devices is a cornerstone of successful collaboration in multi-device environments. In current multi-device environments, communication between personal devices either relies entirely on shared large screens [14, 2, 9, 5, 1, 3, 11] or is achieved through complete screen sharing between devices [20, 15, 13]. However, there are many potential methods and options for information sharing that lie between these two extremes. While some approaches might fall in between these two extremes, there is no comprehensive study that thoroughly evaluates different information-sharing methods specifically in the context of setups involving both large shared displays and personal mobile devices—a scenario that is becoming increasingly common. This

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gap suggests the need for a systematic investigation into different methods of information synchronization within such environments to understand their effectiveness in various collaborative settings better. Furthermore, in collaborative tasks, it is common to involve both familiar and unfamiliar participants, yet prior research has not explored how different information-sharing methods impact the behavior of familiar versus unfamiliar groups. The absence of this exploration indicates a lack of understanding regarding how the dynamics between known and unknown collaborators might influence or be influenced by various synchronization approaches.

Our study addresses these gaps by evaluating three synchronization methods across both **familiar** and **unfamiliar** pairs, providing insights that can guide design decisions for effective information sharing in multi-device collaborative environments. Specifically, we implemented three distinct synchronization methods—**No Sharing**, **Conditional Sharing**, and **Continuous Sharing**—to determine their effects on task completion time, user experience, communication dynamics, and exploration strategies. These methods systematically represent a device coupling spectrum conceptualized by Brudy et al. [2], progressing from isolated work (**No Sharing**), to context-dependent synchronization (**Conditional Sharing**), to constant mutual awareness (**Continuous Sharing**). To evaluate these methods, we conducted a within-subject experiment involving 24 participants (12 pairs), where each pair experienced all three synchronization methods, enabling direct comparison of their impacts. Additionally, the 12 pairs were divided into two categories: **familiar** pairs (participants who knew each other) and **unfamiliar** pairs (participants who did not know each other). We also compared behavioral differences between these two groups across different synchronization methods.

These experiments represent important extensions of prior work. First, we are the first to systematically evaluate three representative information synchronization methods in environments that combine large stationary screens with small mobile devices. Second, we extend our investigation to examine how different levels of group familiarity affect collaboration under varying information synchronization methods.

2 Related Work

Collaboration in digital environments has traditionally been supported by a variety of software solutions, which can broadly be categorized into single-device groupware (SDG) and multi-device groupware (MDG). Single-device groupware refers to systems where all collaborators interact through a single shared device, typically a large display or computer [18]. In contrast, multi-device groupware systems distribute the interaction across multiple devices, including personal and shared screens [18].

Single-device groupware is advantageous in situations where having a unified interaction space is crucial, such as brainstorming sessions around a large, shared display [14, 2, 16]. These systems can effectively foster collaboration by providing a common focal point, which helps ensure all participants are literally and figuratively "on the same page." However, they can also introduce limitations, particularly regarding individual autonomy. In an SDG setup, the lack of personal interaction spaces can hinder users from exploring specific aspects of a dataset independently, which may reduce overall engagement or the depth of insight generation [2, 20, 6].

In contrast, multi-device groupware enables participants to use both shared and personal devices, providing a more flexible collaborative environment. The availability of personal devices allows users to dive deeper into details independently while still contributing to the group's collective goal [17]. This flexibility makes MDG setups especially effective in environments where both shared awareness and individual autonomy are important for task success. The combination of large shared displays for group overviews and personal devices for individualized exploration allows for more fluid role-switching among participants, thereby enhancing both group cohesion and individual productivity [18, 12].

With the rise of wireless communication technologies and improvements in computational power, multi-device collaboration has become increasingly feasible, expanding the design space for co-located collaborative systems [19]. However, managing information flow between multiple devices introduces its own set of challenges. One critical aspect of MDG systems is information sharing—how information is synchronized and presented across devices to maintain a balance between shared understanding and individual autonomy. To address these challenges, researchers have proposed various methods for information sharing in MDG environments, ranging from complete separation to fully integrated views.

1. **Private View Only**: This approach involves each team member using their own device independently, without accessing others' screens or having an overview device (see Fig. 2.a). Brudy et al. [2] identified issues with this method, such as a lack of an overview device, decreased communication, fewer iterations of results, and difficulty attracting attention among team members. Similarly, Wallace et al. [20] observed that independent visualization can reduce task-related discussions, ultimately impacting overall collaboration efficiency. Cambiera's research [6] also found that loosely-coupled collaboration in this mode leads to decreased efficiency and limited information sharing.

2. **Shared Overview Only**: In this approach, each user has a personal device, while an overview of the content is displayed on a shared large screen (see Fig. 2.b). Doring et al. [4] used this method in a digital poker table setup, where private cards were displayed on smartphones, highlighting users' preference for keeping private information on personal devices. Seifert et al. [14], Brudy et al. [2], and Wallace et al. [19] found that Shared Overview Only supports better communication among team members by providing a shared overview, which helps foster tighter collaborations. However, Balakrishnan et al. [1] noted that if users can only observe collaborators' work without modifying it, the overview device may become a distraction, leading to decreased efficiency.

3. **Conditional Access View**: This approach allows participants to access each other's work based on specific conditions, such as active sharing or viewing the same area (see Fig. 2.c). Wallace et al. [20], Shen et al. [15], and Rekimoto and Saitoh [13] have all explored this sharing method, noting that it allows a balance between personal and group views, making it easier for individuals to stay informed while maintaining personal workspace. Homaeian et al. [5] found that conditional access promotes closer coupling of activities, increased communication, and improved collaboration efficiency.

4. **Integrated View**: This approach combines the overview view with users' private views, enabling them to see team work directly from their personal devices (see Fig. 2.d). Brudy et al. [2] demonstrated that integrated view supports continuous communication and alignment among team members by allowing direct engagement with the shared content from personal devices. Isenberg et al. [6] noted that while integrated view can facilitate closer group coupling, it may also reduce individual workspace, potentially impacting tasks that require independent focus [8].

Despite previous research proposing various information-sharing methods in multi-device environments, comparisons have typically focused on specific device contexts or only examined a subset of these methods. In our study, we consolidated the first two modes, **Private View Only** and **Shared Overview Only**, into a single **No Sharing** condition, where users cannot access their partner's

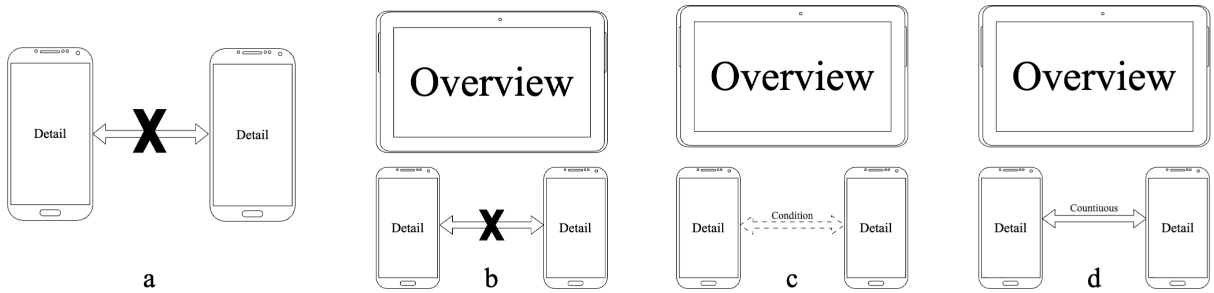

Figure 2: Different information sharing functions: **Private View Only** (a), **Shared Overview Only** (b), **Conditional Access View** (c), **Integrated View** (d).

contributions on their personal devices and must rely on the shared large display to gain awareness. Therefore, our study is the first to comprehensively explore the impact of different information-sharing methods on user collaboration within an environment comprising a fixed large display and small mobile screens. This research aims to provide a more holistic understanding of how different approaches to information sharing influence collaborative dynamics, offering valuable insights for the design of more effective multi-device collaborative systems.

3 *TravelTogether*: Collaborative Trip Planning

To explore the impact of different methods for synchronizing personal device information in a large screen-centric multi-device collaboration, we developed a collaborative Android application named *TravelTogether*. This app was specifically designed to investigate information-sharing methods between personal devices, building on prior research which has demonstrated the benefits of using shared large displays to present global information [18, 2]. Thus, our focus is on how different ways of sharing information between individual devices impact user collaboration and decision-making in a multi-device environment.

Inspired by previous work [9, 2], the task chosen for evaluation was collaborative travel itinerary planning, a representative and commonly studied task in multi-device environments, as it involves significant levels of collaboration in terms of route planning, decision-making, and information sharing. Such a task effectively simulates the type of collaboration that requires both shared overview information and individual exploration. *TravelTogether* was developed to support simultaneous route exploration and planning for two users, who are each equipped with a personal mobile device (smartphone) connected to a shared large display. Users can explore the map and modify the itinerary (e.g., adding, deleting, or reordering points) on their personal mobile devices, while the shared large screen serves as a persistent overview to support group awareness and displays the complete itinerary at all times (see Fig. 3).

In other words, *TravelTogether* provides two views for each user: **Overview** (shared large screen) and **Detail** (personal small screen). Both views show the same map (sourced from Google Maps) with 20 optional attractions labeled, categorized into outdoor attractions, indoor attractions, shopping malls, and hotels, each represented by a distinct color and icon.

On their personal devices, users can zoom and pan to see either a general overview or localized details. They can also click on each attraction to see a detailed description and estimated visit duration (see Fig. 1.a). Attractions can be added to the itinerary by selecting the "add" button, and the sequence of visits can be rearranged through a selection operation. The complete itinerary is connected visually with blue arrows, and attractions added by different users are distinguished by colored flags (see Fig. 3). Users can also remove attractions or adjust the order of visits. The shared large screen displays the full map and the itinerary. At the same time, colored rectangles indicate the views currently displayed on the users' personal devices, providing a sense of their current focus. A progress bar at the bottom of the large screen indicates the remaining available travel time (see Fig. 1.b).

TravelTogether supports three different modes of information sharing between users' personal devices: 1) **No Sharing**, 2) **Conditional Sharing**, and 3) **Continuous Sharing**, each of which represents a distinct approach to synchronizing information between individual devices during the collaborative planning process.

1. **No Sharing.** As shown in Fig. 3.a, users can only see the attractions themselves-added or edited on their own devices. Information added or modified by the other user is visible only on the shared large screen, meaning that the complete itinerary is only accessible there. This method represents a scenario in which personal exploration in a multi-device environment is entirely independent of the influence of others, allowing each personal device to be used purely for individual exploration.

2. **Conditional Sharing.** As shown in Fig. 3.b, users can view each other's contributions and views on their personal devices only when their viewports overlap. This approach allows context-aware information synchronization during collaboration. When two users are focused on the same area, they are more likely to need to communicate and make joint decisions. Previous research has shown that users often require communication when they converge on the same area [2, 18, 19]. Therefore, real-time synchronization during this phase can facilitate awareness of the current collaboration state.

3. **Continuous Sharing.** As shown in Fig. 3.c, users can always see the attractions added by their partners on their own devices. The minimized overview in the lower-left corner of the mobile device shows the same content as the large screen, including the rectangular viewport and the entire itinerary. This approach keeps information sharing consistent and up-to-date between partners, ensuring a coherent collaborative environment, albeit at the expense of some degree of personal exploration autonomy.

4 Experiment

Using *TravelTogether*, we explored how three different information synchronization methods affect user performance and experience in a two-person, multi-device collaborative environment, as well as the impact of familiarity between groups.

4.1 Participants

We recruited 12 pairs of participants (12 female and 12 male) in groups of 12 from a local university and via convenient sampling, aged 18 to 25, who were all students (both undergraduate and graduate) proficient in using smart devices. Six groups were **familiar** with each other, which means they had worked together on at least

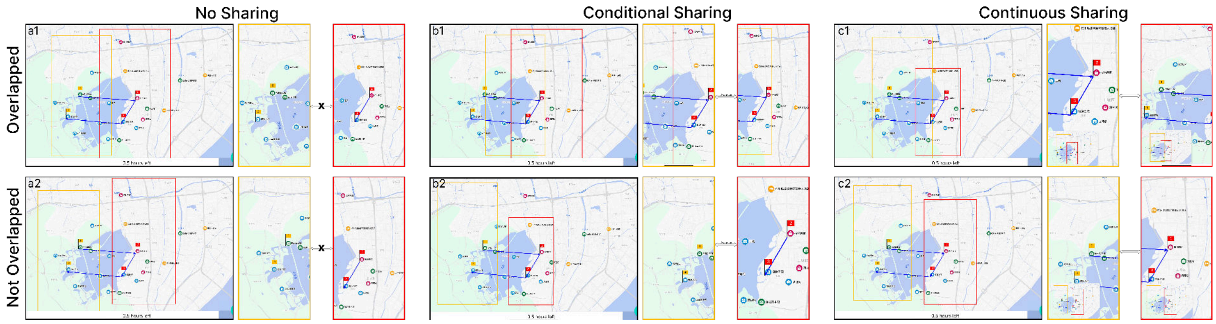

Figure 3: Three sharing methods: (a) **No Sharing**, (b) **Conditional Sharing**, (c) **Continuous Sharing**, in overlapped and non-overlapped scenarios.

one project or regularly communicated within the last six months (like roommates). The remaining six pairs were randomly assigned and were completely **unfamiliar** with each other

4.2 Experiment Design

We conducted a within-subject experiment to investigate the effectiveness of different information-synchronization modes in collaborative trip planning. All participants were asked to use three city maps (Nanjing, Suzhou, Hangzhou) to plan trips under three distinct information-synchronization modes: **No Sharing**, **Conditional Sharing**, and **Continuous Sharing**. We employed a Latin square design to balance the assignment of maps and synchronization modes, ensuring that each map-mode combination was experienced equally across groups.

To control the difficulty, each map featured twenty randomly spaced optional attractions, categorized as follows: eight outdoor attractions, five indoor attractions, three shopping malls, and three hotels. Different icons were used to represent each type of attraction, enabling participants to identify them on the map quickly.

Each pair of participants were asked to plan a 7-hour trip to each city. To be specific, their trip routes were asked to include all types of attractions (outdoor attraction, indoor attraction, shopping mall, and hotel), and to ensure that the hotel was added at the end of the itinerary. Additionally, participants were asked to minimize backtracking and unnecessary detours to ensure that their planned routes were optimal. The experiment was structured to be completed as efficiently as possible, while maintaining adherence to these constraints. Through mobile devices, users can explore and view detailed information about each attraction, including descriptions and the time required for each visit (see Fig. 1.a). They can also add or remove attractions from the itinerary or adjust the sequence of attractions within the route. The complete itinerary and the remaining available time are displayed at the bottom of the large screen (see Fig. 1.b).

4.3 Procedure

Fig. 4 illustrates the entire experimental procedure and divides it into four sections.

1) Introduction. The experimenter introduced the objectives of the study, the application (*TravelTogether*), and the entire experimental procedure. Participants also completed informed consent forms at this stage.

2) Training. Participants were given an opportunity to familiarize themselves with the application and its functionalities. Using an example map not included in the formal experiment, they practiced using the app to explore different information synchronization methods, search for attractions, and interact with the various features, ensuring they were comfortable with the system before starting the formal experiment.

3) Formal Experiment. In this phase, participants completed the main tasks. Each pair was asked to plan a 7-hour trip for three different cities (Nanjing, Suzhou, Hangzhou) using each of the three information synchronization modes: **No Sharing**, **Conditional Sharing**, and **Continuous Sharing**. The synchronization modes were presented in a randomized order to avoid potential bias. Each task lasted approximately 8 minutes, and the experiment lasted about 35 minutes. Participants were expected to complete a full itinerary that included different types of attractions, ensuring that the planned routes adhered to the given requirements.

4) Questionnaire and Interview. After completing the experiment, participants completed a post-study questionnaire to evaluate the effectiveness and efficiency of the three modes of collaboration and their impacts on users' satisfaction, communication and awareness, and intention to use in the future. They then participated in a semi-structured interview to share their preferences and opinions on the three methods.

4.4 Data Collection

The following data were collected during the experiment:

- **Completion Time.** The experimenter manually recorded the time taken to complete each trip-planning task.

- **Note Taking.** The experimenter documented noteworthy participant behaviors, interactions, and group dynamics observed throughout the study

- **Video Recording.** All sessions were video-recorded to facilitate the analysis of participants' collaborative patterns.

- **System Logs.** System logs captured users' viewport changes and actions such as adding, deleting, and modifying itinerary items. Touch input on personal devices was also logged at a maximum frequency of once every 50 ms per device

- **Questionnaires and Interviews.** After the experiment, participants completed a five-point Likert scale questionnaire [7], with some questions adapted from Seidert et al. [14]. The questionnaire evaluated the performance of the three information synchronizations in enhancing and improving collaborative planning efficiency and effectiveness, user satisfaction, user communication and awareness, and future usage preference (see Fig. 9 in Appendix). Following the questionnaire, participants participated in a semi-structured interview to gather insights into their preferences, opinions, and overall user experiences.

4.5 Apparatus

Fig. 4 illustrates the devices used in our implementation. *TravelTogether* was implemented on three Android devices: two Redmi 12C smartphone (6.71 inch), and a Vivo Pad Air tablet (11.5 inch). The two smartphones served as personal devices, acting as clients

Figure 4: Overview of the entire experiment procedure; devices used in the experiment (a) and experimental scene (b).

for the application, while the tablet ran the server side of the application. The view displayed on the tablet was projected onto a 65-inch Hisense large screen using data cables, allowing participants to view the large screen directly as a shared overview display. *TravelTogether* utilizes the WebSocket protocol in a server-client model, enabling real-time information synchronization and interaction between the devices. This setup ensured that participants could seamlessly share information and collaboratively plan their trips, leveraging the comprehensive view provided by the large screen.

4.6 Hypothesis

Building upon the foundation laid by previous research [2, 1, 19, 3, 21, 14] and attributes of each method, we hypothesized the following:

H1: **Continuous Sharing** will yield the minimum task completion time of the extensive information exchange it facilitates.

H2: Different information synchronization methods will influence users' collaborative behavior, including communication (**H2a**) and collaborative exploration strategy (**H2b**).

H3: The familiarity among groups will influence the efficiency of collaboration (**H3a**), as well as communication patterns (**H3b**).

5 Results

5.1 Completion Time

Fig. 5.a illustrates the average completion times for the three distinct information synchronization methods. Normality was assessed via the Shapiro-Wilk test, while variance homogeneity was tested with Levene's test. Given that the data did not meet normality assumptions, we employed the Friedman test for analysis. Results from the Friedman test indicated no statistically significant difference in task completion times across the synchronization methods ($p = 0.32$).

Examining the role of familiarity (see Fig. 5.b), a T-test indicated no significant difference in completion times between **familiar** and **unfamiliar** participants ($p = 0.29$), suggesting similar task efficiency regardless of familiarity levels.

5.2 Questionnaire

Fig. 6 presents the scores and distribution across questionnaire items (1 - Strongly disagree, 5 - Strongly agree).

Regarding effectiveness and efficiency, the **Continuous Sharing** method received the highest ratings, similarly excelling in user satisfaction. This underscores that continuous information flow may positively impact user satisfaction within collaborative contexts. In terms of communication and team awareness, **No Sharing** fostered

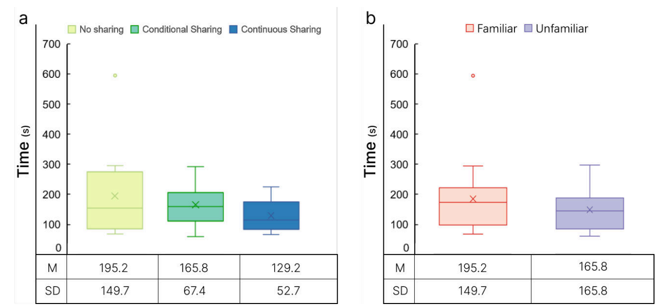

Figure 5: Task completion time for three information synchronization methods (a) and for **familiar** and **unfamiliar** groups (b). In each box plot, the horizontal line represents the mean task completion time, while the "×" symbol indicates the median.

the most communication, while **Conditional Sharing** and **Continuous Sharing** scored moderately. This difference may be attributed to the level of partner visibility; with higher visibility of partner actions, some users may rely less on verbal updates, potentially reducing direct communication. Ratings for awareness also reflect this trend: **Continuous Sharing** best supported users in monitoring partners' work, while **No Sharing** scored the lowest in this regard. For balancing individual and team contributions, **Conditional Sharing** was rated most effective. Lastly, the preference for future use showed a clear favor for **Continuous Sharing**, highlighting its perceived advantages in facilitating collaboration.

5.3 Viewport Changes

As shown in Fig. 7, we analyzed participants' data exploration strategies under each synchronization method (**No Sharing**, **Conditional Sharing**, and **Continuous Sharing**) by tracking viewport coordinates over time. The color-coded viewport frames progressively darken as time advances. We observed similar exploration strategies across different participant groups under varying synchronization methods; participants in all groups consistently explored the same map areas at the same times, indicating synchronized focus regardless of synchronization technique. Furthermore, there were notable differences in viewport changes between **familiar** and **unfamiliar** groups. **Familiar** groups exhibited more frequent viewport changes, suggesting that **familiar** participants operated more actively and delved deeper into data exploration.

5.4 Communication

Fig. 8 illustrates communication patterns across groups. We used dark blue to highlight active communication periods and light blue for the remaining task time to assess the influence of familiarity

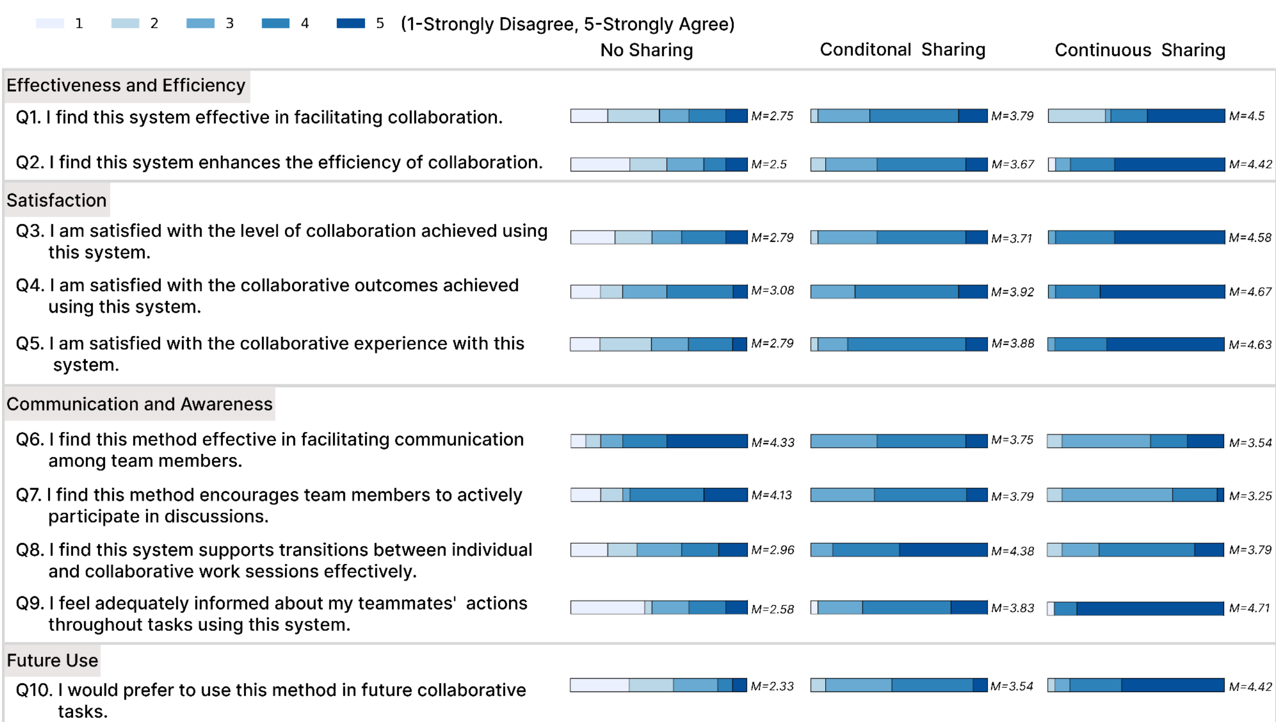

Figure 6: Score distribution of three information sharing methods.

and synchronization methods on communication patterns and frequency.

- **Familiar participants dedicated a higher proportion of time to communication.** As shown in Fig. 8.a, **familiar** groups spent a significantly larger proportion of task time in communication compared to **unfamiliar** groups. A T-test confirmed a statistically significant difference in communication time proportions across familiarity levels ($p < 0.0001 * **$). This suggests that **familiar** participants were more inclined to engage in discussions throughout the task duration, often leading to prolonged communication time overall.

- **Familiarity influenced communication initiation and length per exchange.** **Familiar** groups initiated communication more rapidly, starting within an average of 3.3 seconds, while **unfamiliar** groups took an average of 11.3 seconds to begin. This indicates that **unfamiliar** participants required more time to establish a cooperative rapport. Furthermore, as shown in Fig. 8.b, each communication segment in **familiar** groups lasted longer on average (56.1 seconds per segment) than in **unfamiliar** groups (16.7 seconds per segment). A T-test confirmed this difference was statistically significant ($p < 0.0000 * **$), indicating that familiarity facilitated more sustained conversations once initiated.

- **Limited sharing encouraged more frequent communication among unfamiliar users.** As shown in Fig. 8.c, a post-hoc pairwise comparison revealed a significant difference in the communication-to-task time ratio for**unfamiliar** groups between the **Continuous Sharing** and **No Sharing** conditions ($p = 0.042$). In the **No Sharing** condition (Fig. 8.d), **unfamiliar** participants dedicated more time to communication than those in the **Continuous Sharing** condition, likely due to the need for direct verbal updates without automated information synchronization. For **familiar** groups, however, no significant differences were observed across the synchronization methods, suggesting that established familiarity may promote a robust communication dynamic, potentially diminishing the influence of sharing mode on communication frequency.

5.5 Interview

During semi-structured interviews, participants shared their preferences and suggestions regarding the synchronization methods. A substantial majority (87.5%) favored **Continuous Sharing**, describing it as "more efficient" and "collaboration-friendly" consistent with questionnaire results (Q1-Q4 and Q9-Q10). Some critiques emerged for **Continuous Sharing**, with five participants noting that the overview on personal devices was "unclear," "distracting," or "obstructive." Three participants favored **Conditional Sharing** due to its omission of the overview, which they felt enhanced task focus. **No Sharing** received the most negative feedback, with six participants finding it insufficient; for example, P7 labeled it "meaningless," while P2 and P16 felt that limited visibility impaired collaboration. However, P22 suggested that open communication could offset the lack of shared views.

Participants also remarked on how information sharing affects communication dynamics. Three noted that limited sharing fosters dialogue, whereas extensive sharing in **Continuous Sharing** can reduce verbal interactions. This feedback aligns with responses to questionnaire items Q7-Q8, reinforcing that the balance between shared information and direct communication is critical to effective collaboration.

6 Discussion

6.1 Hypotheses Analysis

H1: **Continuous Sharing** will yield the highest collaboration efficiency due to the extensive information exchange it facilitates.

Contrary to our expectations, **H1 was not supported**: task completion times did not significantly vary across different information-sharing methods. This result diverges from prior studies suggesting that continuous information exchange enhances synchronization and strengthens team cohesion [2, 1, 19, 3, 21]. A possible explanation for this discrepancy may lie in the device setup. Unlike

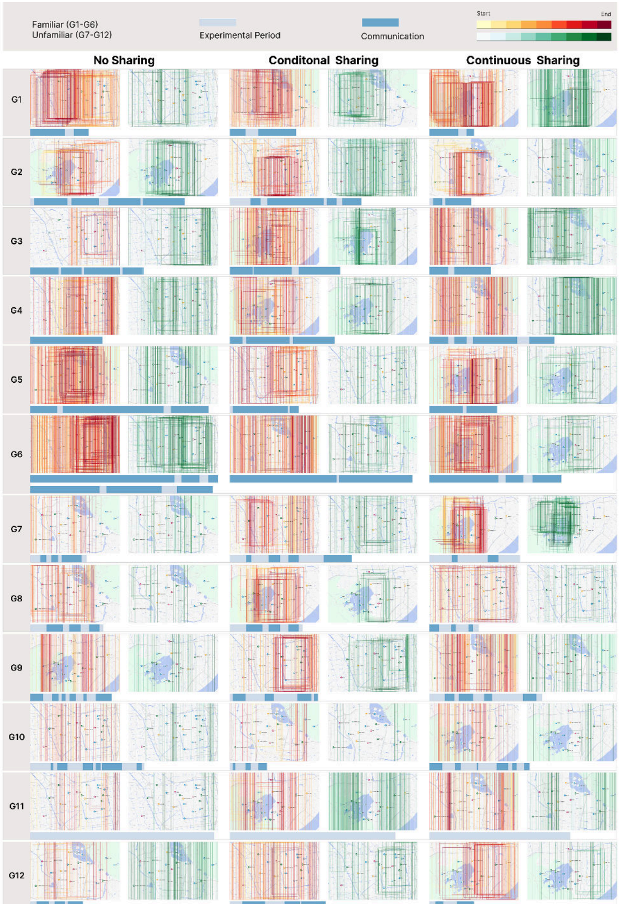

Figure 7: Participants' viewport changes and communication records. A high-resolution version of this figure is provided in the Appendix (see Fig. 10).

prior studies where a shared overview was treated as an optional or dynamic component, our experiment maintained a consistent setup with a dedicated overview device displaying the full route map at all times. This setup likely created a stable shared reference, reducing the impact of synchronization modes on task completion. Consequently, users were able to maintain collaborative alignment across conditions, minimizing the potential efficiency differences among sharing methods.

H2: Different information synchronization methods will influence users' collaborative behavior, including communication (**H2a**) and collaborative exploration strategy (**H2b**).

Our findings provided **partial support for H2**. In terms of communication strategies (**H2a**), the synchronization methods notably influenced the behavior of **unfamiliar** users: limited sharing encouraged more frequent interactions, as **unfamiliar** participants relied on direct communication to fill information gaps (see Sec. 5.4). However, collaborative exploration strategies (**H2b**) were not affected by the synchronization mode, with users tending to explore similar map areas concurrently across conditions (Sec. 5.3). This alignment in exploration may be related to the interdependent nature of the route-planning task. Unlike tasks focused on information gathering [14, 10], which allow for more divergent roles, route planning inherently requires coordinated focus on specific areas, leading participants to concentrate on similar regions irrespective of the sharing method.

H3: The familiarity among groups will influence the efficiency of collaboration (**H3a**), as well as communication patterns (**H3b**).

H3 was supported with respect to communication patterns (**H3b**) but not for collaboration efficiency (**H3a**). Familiarity had no significant effect on task completion times, indicating that the efficiency of completing the task was not contingent on pre-existing relationships. However, it had a considerable impact on communication behaviors, as **familiar** groups engaged in more prolonged and continuous exchanges compared to unfamiliar groups (Sec. 5.4). **Familiar** participants maintained stable communication and engaged in additional social interactions, which, while adding to the communication duration, may have strengthened collaborative rapport and information sharing. This suggests that while task efficiency remained constant, familiarity enhanced the quality of interaction, a factor critical to effective teamwork. These findings highlight the importance of interpersonal dynamics and suggest that tools supporting familiarity-building could further enhance collaborative performance.

6.2 Comparison with Previous Studies

In previous studies, Brudy et al. [2] and Seifert et al. [14] both demonstrated that combining a shared display ("overview device") with individual handheld devices can significantly improve collaborative outcomes. Brudy et al. found that adding a dedicated overview device led to more iteration, better error correction, and more democratic decision-making than either no overview or per-device overviews alone. Seifert et al. showed that pairing mobile devices with an interactive surface doubled participants' interaction time on mobiles and increased information exchanges compared to a laptop-only setup. Both studies also reported frequent transitions between individual exploration on personal devices and group discussion on the shared display.

Our work extends these findings by examining, within the shared-and-individual device environment, whether different methods of synchronizing information across devices affect task efficiency and user experience. Unlike previous studies—which focused on the presence versus absence of an overview device—we held the shared display constant and varied only the synchronization strategy. We found no significant differences in task completion time across synchronization methods, suggesting that once an overview device is in place, the choice of sync mechanism has little impact on efficiency. However, participants still expressed clear preferences for how and where information was shared, favoring designs in which the overview and personal displays remained closely aligned. This nuance—efficiency equivalence paired with divergent user preferences—fills an important gap in the multi-device collaboration literature.

6.3 Design Recommendations

1. **Maintain a Stable, Large-Screen Shared View to Support Task Consistency**

In this study, all conditions—**Continuous Sharing**, **Conditional Sharing**, and **No Sharing**—were equipped with a stable, large-screen shared view displaying a real-time, comprehensive route map. This consistent shared display effectively maintained collaboration coherence across different synchronization methods, enabling participants to focus on shared goals without the distraction of individual device view disparities. Interviews noted that the overview on small personal devices (as in **Continuous Sharing**) was sometimes unclear or distracting, reinforcing the value of a stable, larger shared view as a consistent reference. Regardless of the personal device synchronization method used, the presence of the large screen ensured that overall efficiency remained unaffected, even when team members were **unfamiliar** with each other. This highlights the importance of a stable shared display in maintaining collaborative efficiency and coherence, particularly in situations

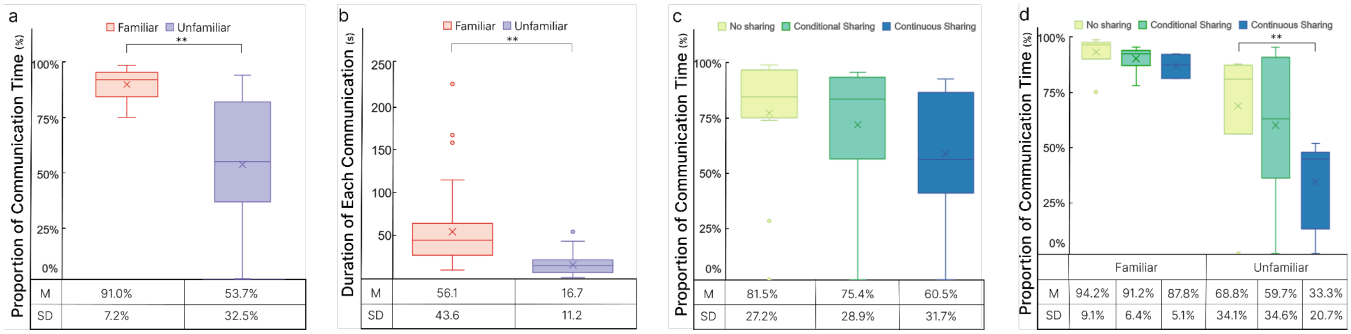

Figure 8: Proportion of communication time in task time by familiarity (a); each duration of communication in familiar and unfamiliar groups (b); Proportion of communication time in task time by information-sharing method (c), and by both familiarity and information-sharing method (d)

where participants lack familiarity with one another. Therefore, future collaborative systems in multi-device environments should consider implementing a stable, large-screen shared view as a unified reference point to support task alignment and reduce the need for additional communication to reconcile individual perspectives.

Design Recommendation: Integrate a stable, large-screen shared view within multi-device collaboration systems to provide a clear, consistent global reference, thereby supporting task alignment and maintaining collaborative efficiency, even among unfamiliar teams.

2. **Design Adaptive Communication Support Based on Team Familiarity Levels and Team Building**

Communication analysis showed that **familiar** teams engaged in longer, more continuous exchanges that often included off-task social interactions, while **unfamiliar** teams communicated more directly and efficiently. This suggests that team familiarity impacts communication strategies, with **unfamiliar** teams benefiting from reduced automatic synchronization (as seen with **No Sharing**), which promotes verbal interaction. Thus, adaptive communication support can be beneficial, particularly for teams with lower familiarity levels, by initially limiting automatic information synchronization to foster interpersonal interaction and progressively increasing it as familiarity develops. Additionally, in cases where collaboration is intended to be long-term, an adaptive approach that gradually increases information synchronization can help foster familiarity and relationship building among team members.

Design Recommendation: Provide adaptive communication modes in the system that adjust synchronization settings based on team familiarity. For less familiar teams, prioritize limited synchronization to encourage verbal interaction and gradually increase synchronization as familiarity builds. For long-term collaborations, start with limited synchronization to encourage familiarity and adapt synchronization levels as the team becomes more cohesive.

3. **Optimize Shared Views for Small-Screen Devices**

Interview results revealed that many users found the overview view on small-screen devices under the **Continuous Sharing** mode unclear and distracting, reducing its effectiveness in supporting collaboration. To improve usability, future designs should consider optimizing the overview display for smaller devices by simplifying content or providing zoom functionalities, ensuring that information remains accessible and usable across different screen sizes.

Design Recommendation: Develop simplified overview for smaller-screen devices that focus on essential task information, while offering detailed visualizations on larger devices to enhance collaborative experience across varied device screens.

These design recommendations, derived from the experimental results, highlight the importance of flexible sharing modes, a stable shared view, adaptive communication settings, and device-optimized views for enhancing multi-device collaboration software. This guidance provides targeted strategies for addressing diverse team needs and optimizing user satisfaction and efficiency in collaborative tasks. However, we acknowledge that the current study employed a relatively simple collaborative task (trip planning) and a homogeneous participant group (university students). Therefore, the findings may not fully generalized to more complex scenarios or to more diverse user populations. Future work could explore these findings in more diverse settings and with a wider range of participants.

7 Conclusion

This study compared three large-screen-centered information-sharing methods in collaborative planning tasks, specifically examining how two participants navigate a one-day trip planning scenario through three distinct strategies: (1) **No Sharing**, (2) **Conditional Sharing**, and (3) **Continuous Sharing**. Of these methods, **Continuous Sharing** garnered the most positive user feedback, suggesting that continuous, real-time information access enhances user satisfaction in collaborative contexts.

While no significant differences were found in task completion times across the different information-sharing methods—likely due to the shared large-screen view, which may have helped standardize information access across conditions—our results underscore distinct effects on communication dynamics. Limited sharing, for example, was found to encourage more effective, direct interactions among **unfamiliar** participants, who relied on verbal communication to compensate for reduced information visibility. Additionally, while familiarity between team members did not directly improve collaboration efficiency, it did lead to more sustained and cohesive communication patterns, highlighting the importance of familiarity in supporting stable collaborative interactions.

These findings emphasize the need to consider both task design and team composition in developing collaboration tools, particularly in multi-device environments. Effective collaboration tools should account for varying levels of user familiarity and adapt information-sharing settings to balance task efficiency with communication needs. By incorporating flexible sharing options, stable shared views, and familiarity-enhancing features, future collaborative systems can better support diverse user needs and improve overall collaboration quality. This study's insights contribute to advancing the design of multi-device collaborative systems, offering actionable guidance for optimizing team dynamics and user satisfaction.

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