Can Real-Time Gaze Sharing Help Team Collaboration? A Preliminary Examination of its Effectiveness with Pairs

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Abstract

Complex and dynamic domains rely on operators to collaborate on multiple tasks and cope with changes in task demands. Gaze sharing is a means of communication used to exchange visual information by allowing teammates to view each other's gaze points on their displays. Existing work on gaze sharing focuses on relatively simple task-specific domains and no work-to-date addresses how to use gaze sharing in data-rich environments. For this study, nine pairs of participants completed a UAV search and rescue command-and-control task with three visualization techniques: no gaze sharing, gaze sharing using the real-time dot, and gaze sharing using the real-time fixation trail. Our preliminary results show that performance scores using the real-time fixation trail were statistically significantly higher than when no gaze sharing was present. This suggests that the real-time fixation trail is a promising tool to better understand operators' strategies and could form the basis of an adaptive display.

Keywords

Team Collaboration, Eye Tracking, Gaze Sharing, Display Design, UAV Operations

Introduction

Team collaboration has become an integral part of every workplace. Working in teams, whether it is in-person or online, has shown to have numerous advantages to dynamic and data-rich domains such as aviation (McNeese et al., 2018), military (Meslec et al., 2020), and healthcare (Gorman et al., 2020). Like many tasks, collaboration requires proper communication between team members to ensure the success of the task with optimal performance. In many cases, these tasks may require continuous attention from team members and a set strategy to prevent any fateful accidents (e.g., medical surgeries, Salas et al., 2008). In one instance, an unmanned aerial vehicle (UAV) crashed into the ground, with the accident later attributed to a lack of coordination between the operators handling the UAV (Williams, 2006). Therefore, unless teamwork is carefully considered and appropriately managed in real-time, the overall team performance may be compromised (Atweh et al., 2022). Real-time feedback in team displays can be a valuable tool for teams looking to improve their communication, collaboration, and performance. By providing timely and relevant feedback, teams can make more informed decisions, work more effectively together, and achieve their goals more efficiently (Laskowitz et al., 2022).

Using speech to communicate spatial information can be difficult and time consuming because individuals often lack a shared reference frame to specify precise target coordinates (Logan & Sadler, 1996). Rather, they must construct impromptu coordinate systems and use potentially ambiguous referring expressions that take several speaking turns to succeed. Researchers are in continuous search for real-time methods and optimal display designs that aid team collaboration and facilitate communication. One way to gain insight of team collaboration and individual attention allocation is using eye tracking, an infrared-based technique that provides a trace of people's eye movements (Gidlöf et al., 2013). Eye tracking is a promising means of supporting operators in real-time. Understanding what teammates are looking at and when can provide insight into how the performance results came about which cannot be obtained through other means such as surveys, questionnaires, or debriefing participants at the conclusion of a study. Several eye tracking metrics have been used to measure team performance such as pupillometry metrics (Daggett et al., 2017), gaze overlap (Pietinen et al., 2010), scanpath similarity (El Iskandarani et al., 2023), and cross-recurrence metrics (Atweh et al., 2023; Cherubini

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et al., 2010). However, there has been limited work looking at gaze sharing, i.e., how to visualize eye tracking measures in real-time between teammates.

Related Work

Gaze Sharing

Gaze sharing is a means of communication used to exchange visual information between teammates as it allows partners to view each other's gaze points on their respective displays while simultaneously completing their tasks. This method has proven to be effective in enhancing performance, efficiency, completion time, understanding and collaboration within teams in relatively simple, task-specific domains such as assembling puzzles (Lee et al., 2017), looking for an O among Qs (Zhang et al., 2017), and building Lego models (Gupta et al., 2016). It has allowed researchers to detect learned patterns, in which users settle on strategies by following their partners' gaze points, while completing the experiment (Niehorster et al., 2019).

Gaze perception has been investigated as a means to understand the process of collaborative reference, establish joint visual attention, and improve physical task performance (Keita et al., 2016). For example, Schneider and Pea (2017) found that mutual gaze perception intervention helped students achieve a higher quality of collaboration and a higher learning gain. On another hand, gaze sharing may induce attentional costs that can possibly outweigh its benefits leading to less desirable results (McCarley et al., 2021). As more data and elements are being incorporated into various work domains, it becomes essential to study how gaze sharing impacts individual and team performances.

Gaze Sharing Visualization Techniques

Gaze sharing involves overlaying teammates' gaze points onto each other's displays. This overlay is done using different choices of visualization techniques, some of which are: dot, spotlight, heatmap, fixation trail, etc. Other choices have been adopted by researchers, utilizing fixations and saccades, such as the fixation map (where fixations are represented by circles, and saccades are represented by lines connecting the circles), highlighting the areas of focus and the users' gaze path (Špakov & Miniotas, 2007). These techniques are often evaluated based on their ease of implementation (i.e., the amount of data required to generate the visualization), level of informativeness to the user, precision in capturing the user's real eye movements, and degree of distraction (Newn et al., 2017).

Although these factors are mainly influenced by the shape, color, and opacity of the visualization technique, the complexity of the display highly affects how evident or distracting a representation is. This implies that the design of gaze visualizations directly affects the users' mental demand, team coordination, and performance. Table 1 presents the most prominent visualization techniques found in the literature alongside their advantages and disadvantages. Early work in gaze sharing suggests a potentially better way to communicate spatial information that utilizes deictic cues, such as cursor movements (Brennan, 2008). Cursors are efficient tools for communicating spatial information since they are immune to the triangulation errors that limit the usefulness of finger pointing or line-of-sight estimates. When used with cursors, speech would presumably serve mainly as an alerting function in a spatial-referencing task, enabling one person to easily tell another when to use the deictic information from the cursor. A commonly used visualization technique recently is the coordinate-based dot symbol that has mostly been adopted for its simplicity and minimal mental load (Li et al., 2019). Jing et al. (2022) studied gaze behavior to detect overlapping gaze between teammates. For instance, two overlapping gaze points turned green to inform the users of their mutual gaze. This technique allowed players to accordingly modify their strategies based on their partner's current area of interest. Other studies used heatmaps and trajectory-based visualizations to maintain the user's past gaze history for a specific time span (Zhang et al., 2017). This extra information provided higher accuracy in locating the partner's area of interest, while it induced more distraction and cognitive labor on users.

Accordingly, this current study adopts a complex display, where users are expected to avoid target objects, while correctly monitoring and maintaining the health status of the UAV. The experiment includes real-time sharing of the operators' gaze points, with synchronization of each individual's actions, reflected on their teammate's display. This evaluation of gaze sharing techniques in complex domains has not yet been recorded in the literature, which allows us to target this gap and open opportunities for future research to look into gaze sharing in real-life scenarios. We expect that our gaze visualizations will help improve performance (Jing et al., 2022; Li et al., 2019).

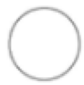
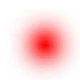
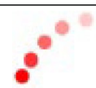
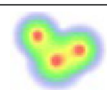
Methodology

Participants

18 participants (nine pairs in total) of undergraduate and graduate students at the University of Virginia were recruited for this study (M = 23.5 years, SD = 2.63 years). Each pair consisted of one male and one female who did not previously know each other aiming to control the variables and reduce potential confounding factors that could influence the results. The experiment was approved by the University of Virginia's Institutional Review Board (IRB-SBS #3480) and lasted approximately 75 minutes.

Participants read and signed the consent form and were then briefed about the experiment's goals and task

Table 1. The type, description, visualization form, advantages, and disadvantages of existing gaze sharing visualization techniques.

Type	Description	Visualization Form	Advantages	Disadvantages
Dot	Translucent colored dot		- High precision in translating user's gaze - Allowed users to process visual information quickly	- Can be potentially distracting - Quick jittery movements - High visual information: amount of gaze data
Cursor	Large ring with transparent center		- Equivalent to size of foveal vision - Provides more visual info (what's enclosed inside)	- Can be potentially distracting - Quick jittery movements - Low visibility
Spotlight	A circle with high opacity in the center and decreasing opacity towards the edges		- Less distracting - Moderate visual information - Informative	- Low visibility (can't see inside it) - Quick jittery movements
Fixation Trail	Uses fixation data and leaves a trail of fixations		- Users know previous fixation states - Moderate visibility	- Can be potentially distracting
Heatmap	Represents the distribution of gaze points by a color gradient		- Informative	- Occludes parts of the display

expectations as a pair. Participants then independently completed a five-minute training phase. By the end of training, participants had to demonstrate they could achieve 70% accuracy for all tasks. We then informed the pairs about how the simulation was networked and provided them with three minutes to introduce themselves to one another and discuss anything they deemed necessary. There were no restrictions on how the participants could interact during these three minutes, i.e., the experimenter gave no guidance on what should be discussed, so discussing team strategies before the experimental portion was completely participant-driven. Participants could communicate verbally with each other during the experiment. The same tasks appeared at both stations and the actions of each team member were reflected on both stations, but a participant could not see the cursor movements of their teammate.

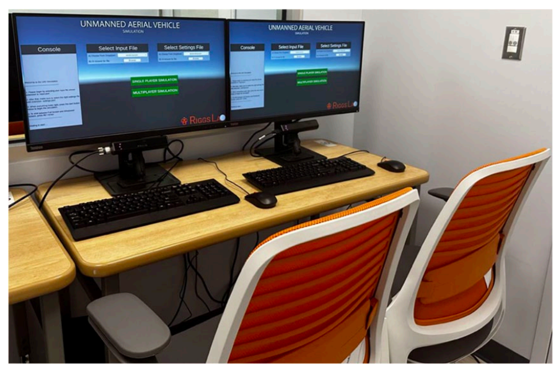


Figure 1. The experimental setup with the two networked desktop computers side-by-side.

Experimental Setup

The design of the simulation was based on the 'Vigilant Spirit Control Station' the Air Force uses to develop interfaces to control multiple UAVs (Feitshans et al., 2008; Figure 1). Pairs were collocated, but each participant viewed separate monitors and used separate mice to input responses. The simulation was networked so participants could see inputs from their partner in real-time (e.g., when Participant 1 responded to a chat message, Participant 2 could see his/her response in real-time). Two desktop mounted FOVIO eye trackers with a sampling rate of 60 Hz were used to collect point of gaze data. The average degree of error for this eye tracker is 0.78° (SD = 0.59°; Eyetracking, 2011).

UAV Tasks and Point Values

Each pair of participants was responsible for managing up to 16 UAVs which involved completing a primary target detection task and three secondary tasks (Figure 2). These tasks and their structure emulate the multitasking, dynamic, and interdependent environment of a UAV command and control. The four tasks were as follows:

1. *Target detection task (primary task)*. Pairs monitored each UAV's video feed and indicated whether a cube was present—i.e., the target. When a UAV was approaching a waypoint (i.e., a predetermined area of interest denoted on the Map panel), its video feed could become "active" (i.e., video feed became

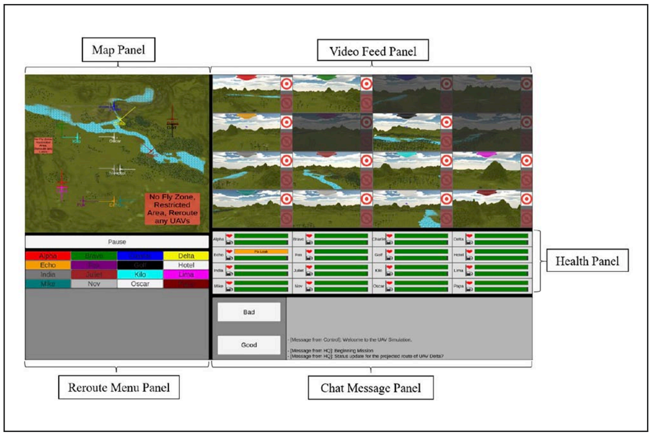


Figure 2. Screenshot of the UAV simulation with the four panels labeled (clockwise): Map, Video Feed, Health, Chat Message, and Reroute Panels.

Table 2. Point system used to assess performance.

Response	Points Per Response
Correctly recognizing a target	+100
Correctly recognizing a non-target	+50
Completing any secondary task (i.e., reroute, fuel leak, and chat message)	+30
An incorrect or no response to any task (e.g., false positive or no response to the target detection task, UAV flies through a *no-fly-zone*, or a UAV health is not maintained)	-100

highlighted; Figure 2). If a semi-transparent cube appeared while the video feed was active, the pair was instructed to press the target button to indicate

2. a target was present; if no target was present, then no response was necessary as this was the default option. Pairs were instructed that the target detection task had the highest priority among the four tasks.
3. *Reroute task (secondary task)*. Pairs were tasked to reroute a UAV when it was projected to enter a no-fly-zone, denoted by a red square on the Map panel (Figure 2; red square labeled "Reroute any UAVs that enter this area" in the Map Panel). To reroute a UAV, a participant clicked on the respective UAV's numbered square in the Reroute Menu panel to activate the reroute menu which listed three alternative route options. Participants could click 'Preview' to see a specific alternative's suggested route. When a UAV was not rerouted in time (i.e., the UAV entered a no-fly-zone) it would be decommissioned and would no longer be able to complete the remainder of the mission.
4. *Fuel leak task (secondary task)*. Pairs were tasked to monitor and maintain the overall health of each UAV. Participants used the Health Panel, which consisted of a health status bar and fuel level bar for each UAV (Figure 2). One instance where a UAV would need assistance is if it experienced a fuel leak, which consisted of the UAV's fuel level bar rapidly decreasing in fuel, the color of its health status bar changing from green to yellow, and the message "FIX LEAK" appearing in the health status bar. To stop a fuel leak, the participant clicked on the health status bar. This would change it back to green and stop the fuel from decreasing rapidly. If the leak was not stopped in time, the UAV would reach the "FATAL FUEL LEAK" condition and the task could no longer be completed.
5. *Chat message task (secondary task)*. Pairs were tasked with responding to messages from headquarters by selecting one of two options on the left-hand side of the chat message panel (Figure 2). They were told to respond to as quickly and accurately as possible.

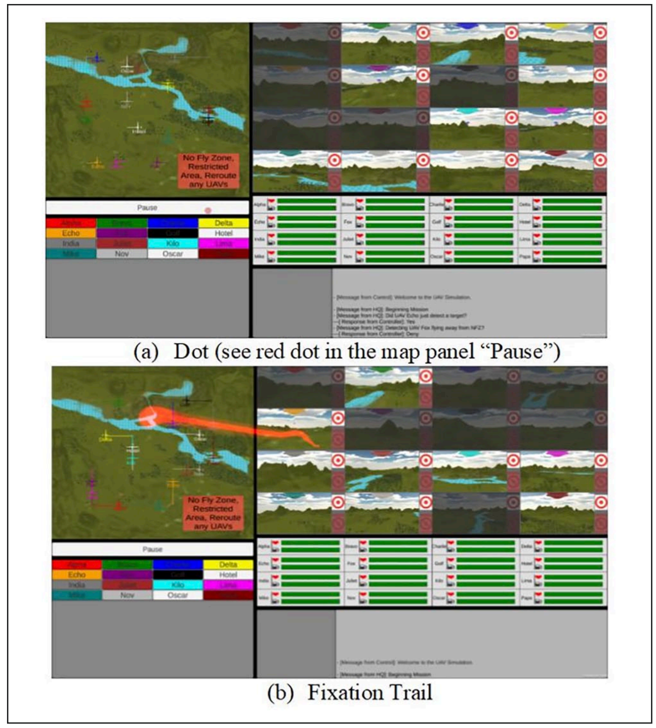


Figure 3. The dot (a) and fixation trail (b) gaze sharing visualization techniques used in this study.

Between each pair of participants, only one participant from each pair would have to complete each instance of a task. Table 2 shows the point value associated with each task. Points were assigned to emphasize the priority of the primary task (i.e., target detection) as well as to convey the severity of incorrectly or not attending to a task (e.g., UAV flies through *no-fly-zone*).

Experimental Design

For this study, we manipulated three visualization techniques. A within-subjects experiment was conducted, in which each pair performed the task three times, once with no

Table 3. Mean scores across the nine pairs of participants using the three different visualization techniques.

Visualization Technique	Mean Score (SD)
No Gaze Sharing	10,786 (721)
Gaze Sharing Using a Fixation Dot	11,722 (456)
Gaze Sharing Using a Fixation Trail	12,130 (162)

gaze sharing, once with gaze sharing using a real-time fixation dot, and once with gaze sharing using a real-time fixation trail, with order of presentation counterbalanced across subjects. Figure 3 shows the real-time gaze sharing visualization techniques used in this study. The dependent variable of this study was the point system performance metric.

Results

The mean score across the nine pairs in each condition was calculated and the results (mean and SD) are reported in Table 3.

A one-way ANOVA was conducted to check for any statistical difference between the scores of the three conditions, with gaze sharing using a fixation trial having the highest mean score, followed by gaze sharing using a fixation dot, and no gaze sharing. No gaze sharing had the highest standard deviation followed by fixation dot and fixation trial.

The preliminary results of this ongoing effort show that there was a statistically significant difference between groups ($F(2,25)$=9.297, p=.021, η^2=0.467). A Tukey post hoc test revealed that using the fixation trail gaze visualization technique had statistically significantly higher scores compared to when no gaze sharing was present (p=.019). There was no statistically significant difference between the gaze sharing using a fixation dot and fixation trail (p=.369). There was also no statistically significant difference between gaze sharing using a fixation dot and the absence of gaze sharing (p = .165).

Discussion & Conclusion

Although gaze sharing has shown to be effective in improving team performance in relatively simple collaborative tasks such as social interactions (Laskowitz et al., 2022), no work-to-date has examined real-time gaze sharing in more dynamic domains. Moreover, no work has addressed which gaze sharing visualization technique is suitable for which task and how do we choose this technique in real-time.

The present study explored these questions for a UAV search and rescue command-and-control task where teammates are responsible for monitoring and completing several tasks at once. The results here showed that groups who completed the tasks using the real-time fixation trail visualization technique performed significantly better than groups who completed the tasks without gaze sharing—which supports our initial expectation. These initial findings suggest that gaze sharing in general is a promising tool in complex domains and researchers and practitioners should consider gaze sharing using the fixation trail technique in future display design aiming for a better team performance. Moreover, fixation trails in real-time can potentially be used to better understand operators' strategies and could form the basis of an adaptive display.

The results also show that the standard deviation between groups was significantly decreasing from no gaze sharing to gaze sharing with the gaze sharing using the fixation trail having the lowest standard deviation. This shows that the magnitude of variability is low which means that the results are more likely to be consistent, reliable, and generalizable to the larger population. Therefore, low variability helps increase precision and accuracy of the results, reduce the impact of outliers, and increase the chances of detecting small but meaningful differences between groups.

Building from this initial contribution, additional work is needed to further explore other visualization techniques such as heatmaps in similar tasks (Trösterer et al., 2015). Moreover, with a larger sample size, researchers can replicate this work and get a better understanding of the dot visualization technique's effect in comparison to other techniques as well. As per previous work, choosing the right visualization technique remains a very broad question that requires examination of methods and selecting the right one for each task since the wrong choice of visualization may cause distraction and eventually less optimal results (Newn et al., 2017). Future work should address other real-time gaze sharing visualization techniques for other tasks and setups in other complex domains such as healthcare and driving (Atweh et al., 2022).

It is noteworthy to mention as well that researchers in the field have been introducing design recommendations for gaze sharing and trying to understand the effect of communication strategies and tasks in terms of performance only; however, the literature lacks research on how and whether these interfaces support situation awareness (SA). The choice of visualization technique can also primarily have an effect on the operator's SA. As some visualizations are more distracting than others, choosing the wrong visualization for a given task can shift the user's attention to the visualization itself, disregarding important events within the environment (McCarley et al., 2021). This is one of the main reasons for human-error induced accidents in aviation, where pilots lose SA and fail to discern the provided information from the information presented with the flight instruments (Kilingaru et al., 2013). Thus, it is necessary to study gaze sharing in terms of effectiveness in maintaining individual and team SA alongside the overall team performance.

Overall, the findings of this work and other contributions from the field will fundamentally advance research on understanding and designing to support team interaction using adaptive and collaborative displays as a means to support team performance leading to practical improvements in a variety of safety-critical domains. If performance and SA can be improved through system design and real-time measures, it will go a long way towards the ultimate goal of improving human performance and safety in many dynamic domains.

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