The Impact of Supplementary UAV Views on Remote Operator Performance in Teleoperated Driving Interventions

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Figure 1: Driving simulator setup with the participant seeing the front view in the center and the uav view on the right.

Abstract

Autonomous vehicles (AVs) still need human intervention during edge cases. The problem is that remote operators often face limited situational awareness when relying on standard front-view cameras. This study analyses whether an additional unmanned aerial vehicle (UAV) perspective improves remote operator performance in teleoperated driving scenarios. Thirty participants completed three special scenarios (low visibility, obstacle course, and a crowded urban environment, with pedestrians suddenly running on the street) with either front-view only or front-view plus UAV view (between-subjects design). The group with UAV support completed the scenarios quicker, used the UAV view adaptively based on the task, felt more confident and showed signs of higher situational awareness. Although crash rates showed no significant differences, the efficiency improvement supports integrating UAV views in teleoperation systems for better remote driving capabilities.

CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**; **Empirical studies in HCI**; *User studies*; *User interface design*; *Interface design prototyping*; • **Applied computing** → **Transportation**.

Keywords

teleoperation, UAV, situational awareness, autonomous vehicles, remote driving, human factors, nasa-tlx

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1 Introduction

Considering the large number of situations that autonomous vehicles (AVs) might face, it is unrealistic to physically test every possible scenario. Although often rare, these edge cases occur frequently enough to require specific attention to the design [13].

Examples of such cases include extreme weather events [20], low visibility scenarios [8], and sudden pedestrian or animal crossings [1]. Teleoperation serves as a crucial fallback mechanism when autonomous systems face situations they cannot handle independently [1].

Successful teleoperation of a vehicle depends on the operator's ability to stay fully aware of what is happening in the remote environment [3]. Unlike drivers physically inside a car, remote operators rely completely on sensor data transmitted to them to understand the vehicle's surroundings [5]. They must construct a complete mental model of the driving situation without the sensory feedback and background information that in-car drivers experience, as remote operators usually enter the scene only when the edge case occurs [3].

Current teleoperation systems typically rely on standard vehicle-mounted cameras, most commonly providing a front-facing perspective similar to a driver's natural view [9]. While this approach preserves familiarity for operators accustomed to conventional driving, it inherits the same visual limitations, including restricted field of view, limited depth perception [19], and vulnerability to environmental factors such as poor lighting or adverse weather conditions. These limitations reduce situational awareness and may compromise safety during critical interventions [3].

To address this, our study investigates whether providing remote operators with an additional aerial view from an unmanned aerial vehicle (UAV) can improve performance in challenging teleoperation scenarios.

In our work, we embed this approach into the broader problem of teleoperated AV intervention by experimentally comparing operator performance with and without UAV support. By simulating demanding edge case scenarios such as low visibility, obstacle navigation, and sudden pedestrian crossings we assess whether the UAV perspective enhances situational awareness, performance, and cognitive load for remote drivers. Our findings aim to inform the design of future teleoperation systems, answering if the integration of UAV based perspectives may be a promising solution for overcoming the limitations of current camera setups and improving remote driving capabilities in critical situations.

2 Related Work and Research Gap

Recent research has examined challenges in maintaining operator situational awareness during teleoperation, especially when visual information is limited or unclear. One important aspect is the effect of an additional top-down camera perspective, often referred to as the bird's eye view (BEV), on situational awareness. Studies have assessed whether the integration of a BEV into tele-driving interfaces can positively influence situational awareness [2]. For example, remote user tests with pre-recorded driving scenarios revealed that the extra view does not always enhance situational awareness; in some cases, it even made it harder for operators to notice important elements such as distant objects or road signs [2, 7]. The increased cognitive workload caused by switching between multiple views was identified as a possible reason for this effect, as it can make it difficult to focus on key details [11, 18]. It is important to note that these studies were limited by their reliance on video playback rather than fully simulated or real-world teleoperation environments, which may not accurately reflect the actual challenges of remote driving [2]. The authors therefore recommend further research on flexible interface designs, different camera angles, and the optional activation of such views to address these issues. Overall, these findings highlight the importance of keeping interface complexity manageable to avoid overwhelming tele-drivers and indicate that further research is needed to fully assess the impact of additional camera perspectives.

In addition to camera perspectives, the operator's mental state and the driving environment play a significant role in situational awareness and intervention performance. Previous research has shown that both the type of obstacle and the operator's mental workload can affect takeover performance in conditionally automated driving [14]. For instance, moving or dangerous obstacles tend to reduce awareness and slow down response times, while increased mental workload exacerbates these delays. These findings underscore the importance of understanding how additional information or tasks, such as a new camera view, can impact operators. Any extra input must therefore be carefully tested to ensure that it supports rather than hinders awareness and response speed.

Cognitive load is a major factor in human-machine interaction, especially when operators are required to handle multiple tasks simultaneously. Research on measuring cognitive load and its effect on performance in contexts such as flight monitoring and emergency handling has identified metrics like NASA-TLX, SWAT, and PAAS as effective indicators of mental workload. These studies consistently show that secondary tasks increase mental strain and often impair performance on primary tasks [6]. The more demanding the main task, the greater the negative impact of additional tasks, suggesting that mental overload can seriously compromise performance in high-stakes settings. This implies that adding further information, such as a separate UAV view, may slow down interventions and driving performance, potentially outweighing the benefits gained from an improved overview of the driving situation.

Despite the findings, there is still a big gap in knowing how an extra camera view, such as from a tethered UAV, affects operator performance in real-time teleoperated driving. Past studies on bird's eye views and cognitive load often use pre-recorded scenarios or automated driving setups, which do not fully capture the fast-paced and high-pressure nature of teleoperated driving. In addition, research on mental load in multitask situations shows that secondary tasks can drag down main task performance, especially as things get more complex.

This makes it crucial to carefully check if extra inputs like additional camera views boost or hinder operators by piling on mental demands. The potential benefits of UAV views, such as providing flexible real-time environmental awareness, have not been properly studied in teleoperated driving. Filling this gap is crucial, as the adoption of remote driving is rapidly increasing for applications such as autonomous taxi services, remote delivery, and emergency response services, while human intervention remains necessary for unavoidable edge cases. This research could guide the design of future teleoperation systems, making sure extra views are added in a way that boosts operator performance without cognitive overload. It could help create safer, more effective teleoperated driving systems and pave the way for their use in critical real-world situations.

2.1 Research Questions and Hypotheses

After identifying the gap in literature regarding the effects of UAV views on remote operators in real-time simulated experiences, we formulated the following research question:
Does the addition of a supplementary UAV view improve the performance of a remote operator in a teleoperated driving intervention scenario compared to no additional view.
To fully measure the effect of the UAV view on operators, we will create a driving simulation and divide our pool of participants into two groups. One group will have an additional camera view, and the other will not. We will then use Unity to record all driving-relevant data and assess situational awareness and cognitive load using questionnaires.

Our first hypothesis focuses on the core aspect of operator performance. We expect that the supplementary UAV view will provide remote operators with critical information that is otherwise unavailable from the standard perspective. Therefore, we hypothesize that $\mathbf{H1_1}$**:** *The addition of a UAV view in tele-driving scenarios causes a significant increase in driving performance.*

Beyond performance, situational awareness is a key factor in safe and effective teleoperation. The overhead perspective offered by a UAV may help operators better understand the spatial relationships and dynamics of the environment. Thus, we hypothesize that $\mathbf{H2_1}$**:** *A remote operator's situational awareness can significantly increase through the addition of a tethered overhead perspective.*

However, introducing an additional information source may also have drawbacks. The need to process and integrate multiple camera feeds could increase the cognitive demands placed on the operator. Accordingly, we hypothesize that $\mathbf{H3_1}$**:** *Providing remote operators with an additional UAV view during tele-driving scenarios significantly increases cognitive load.*

3 Methods

We conducted a simulation-based study to examine how different visual perspectives affect remote driving. Participants were assigned to one of two groups: one received only a front view from the vehicle's perspective, while the other had access to both a front view and an additional aerial view from a UAV. These visual perspectives were presented on two separate screens: the front view was displayed on the center screen, and the UAV view on a second screen positioned to the right. All participants navigated through three scenarios designed to reflect typical challenges in teleoperation. A detailed description of the structure is provided in the following sections.

3.1 Sample

We conducted the study using a between-subjects design comparing two groups: The control group (front view only, n = 15) and the UAV view group (front view + UAV view, n = 15).

In the front view group 9 men, 4 women and two people deciding not to answer took part of our study. In the UAV group 4 women, 9 men and 2 people deciding not to answer participated.

The participants were grouped into four age ranges: n = 3 were between 18 and 20 years old, n = 20 between 21 and 24 years old, n = 6 between 25 and 34 years, and one participant did not provide their age.

3.2 Simulation

To examine the influence of different visual perspectives on remote driving, we developed an interactive simulation environment using Unity. Within this virtual setting, participants remotely controlled a shuttle bus through a realistic urban environment. A short tutorial was included to help participants with controlling the vehicle. Each of the three main driving scenarios represents a specific challenge in remote vehicle operation.

The general context across all scenarios involved an emergency situation in which the autonomous driving system of a shuttle failed, requiring a human operator to remotely take control of the vehicle while passengers remained on board. Participants took on the role of the remote operator and were tasked with safely navigating the shuttle through the three scenarios described in figure 2.

3.3 Procedure

3.3.1 Introduction. Upon arrival, participants were welcomed and informed about the study's purpose, procedure, and their rights, including data privacy and the option to withdraw at any time. After signing the consent form, they completed a short demographic questionnaire. Subsequently, participants familiarized themselves with the driving setup through a short tutorial in a virtual city environment. They adjusted the seat, practiced basic vehicle controls (e.g., acceleration, braking, reverse), and learned about the vehicle's dimensions by observing an identical shuttle in the scene. The tutorial concluded with a slalom course to train spatial awareness and vehicle handling. Throughout the session, the experimenters were seated behind the participants and remained outside of their field of view in order to minimize distraction and ensure a naturalistic driving experience. After completing the tutorial, participants were equipped with the eye tracking device and proceeded to the main driving tasks.

3.3.2 Completion of Driving Scenarios. Each participant completed three driving scenarios in order as seen in figure 2. After the first and second scenario, they answered a NASA-TLX questionnaire to assess their perceived workload. Following the final scenario, participants answered open-ended questions about their experience and rated their sense of control on a 7-point scale. At the end of the study, participants completed a final survey addressing all three driving scenarios.

3.4 Study Design

The study included two conditions, with a total of N=30 participants assigned to each in alternating order. The sample size was determined based on the usual number of participants in the module in which this paper was written to do proper justice to the time required and to obtain comparable results with a large effect size. In the first condition, participants received two visual perspectives: a front view from the vehicle's perspective and an additional UAV view, offering a bird's-eye perspective. In the second condition, participants received only the front view from the vehicle's perspective without any additional perspectives. By comparing these

(a) Scenario 1: Low visibility night drive with dense fog and a narrow construction zone with cones, barries and parked vehicles

(b) Scenario 2: Windy day urban environment with debris and trash bags scattered across the road

(c) Scenario 3: Crowded urban environment with pedestrian activity and children suddenly emerging from behind a parked bus

Figure 2: Depiction and description of the three scenarios all participants completed in the shown order

two conditions, the study aimed to evaluate how the presence of the aerial view affects remote driving and situational awareness.

3.4.1 Between-Subject Study Design. The choice of a between-subjects design in this study was based on several considerations. Each participant was assigned to only one of the two experimental conditions, either front-view only or front-view combined with a UAV perspective, which helped to minimize the duration of each session. This was beneficial for the recruitment of participants and helped them maintain concentration and motivation throughout the study.

More importantly, the design was chosen to ensure internal validity. If participants were to complete both conditions, they would either repeat the same scenarios, resulting in anticipatory behavior and carry-over effects, or face different scenarios, introducing unwanted variability. In both cases, performance could be influenced by factors unrelated to the experimental manipulation. A between-subjects design avoids these risks by eliminating cross-condition learning, practice, and order effects. Given the nature of driving tasks and the potential for knowledge transfer between runs, this approach was considered to be the most appropriate to ensure valid results.

3.4.2 Variables. The independent variable in this study was the type of visual view provided to the remote driver, with participants assigned to a front view only condition or a front view combined with a tethered perspective condition.

Dependent variables covered both quantitative and qualitative measures. Quantitative data included driving metrics such as task completion time, collision counts, and eye-tracking metrics reflecting gaze patterns. Qualitative data consisted of NASA-TLX workload questionnaires and additional questionnaires assessing user experience and situational awareness.

3.4.3 Final Survey. The final questionnaire captured participants' overall impressions across all three scenarios, including perceived challenges, navigation strategies, and feedback on the remote driving interface. Those in the aerial view condition were also asked when and why they used the UAV perspective.

Additional questions addressed spatial orientation and potential difficulties encountered during the tasks. The responses provided insight into participants' strategies, preferences, and perceived benefits or limitations of the visual setup. Qualitative answers were analyzed using inductive clustering, revealing recurring themes such as spatial awareness, situational understanding, and positive or critical feedback on the UAV view.

Figure 3: Driving Setup with an adjustable chair, pedals, steering wheel and a person wearing eye tracking glasses

3.5 Apparatus

3.5.1 Driving Simulation. The driving simulation was developed in Unity3D and featured various traffic situations, including city environments and construction zones, to create realistic and challenging driving conditions.

3.5.2 Driving Setup. The driving setup included an adjustable car seat to ensure a comfortable and realistic driving posture. Steering was controlled using a Logitech G29 steering wheel equipped with paddles used to shift between reverse, neutral and drive. Since the vehicle had an automatic transmission, no additional gear shifting was required. Throttle and braking were operated via separate pedals that were placed on the floor, replicating a real driving experience.

Participants were positioned in front of two displays providing visual information for the simulation. Depending on the assigned experimental condition, either one or both screens were used to present the driving views. The center screen displayed the front view, including information such as the tachometer, speedometer, and gear selection. The right screen was used for the UAV view.

3.5.3 Eye Tracking System. An eye-tracking device was used to record participants gaze behavior throughout the driving tasks. The system featured an outward-facing camera to capture the surrounding environment and inward-facing cameras to track the participants fixations, allowing precise identification of where they looked during the simulation.

We used the pupil labs cloud reference image mapper feature to map the gazes onto both screens for UAV group, which we defined as areas of interest (aio), in order to gain relevant insights [15]. We had to map 8 of the 40 Scenarios by hand, as the mapper failed to identify the screen the participants looked at. Afterwards the enrichment returned us a file with the following data for every scenario recording and aio:

- average fixation duration in ms
- total fixations
- time to first fixation in ms
- total fixation duration in ms

We also placed tracking markers on all screens edges as seen in figure 1, that we wanted to use with a Marker Mapper, sadly the video quality, especially the motion blur when the participant turned their head made the Marker Mapper unreliable.

4 Measures

4.1 Quantitative Measures

Measurement	Description
Completion Time	Time in s from starting the scenario till completion
Throttle Time	Time in s from first throttle input till completion
Total Crashes	Total amount of crashes that occured
Current Speed	current speed logged every gameupdate
Currently Reversing?	if the bus is currently reversing logged every gameupdate
Throttle Input	Input to the throttle pedal logged every gameupdate
Brake Input	Input to the brake pedal logged every gameupdate
Steer Input	Position of the steering wheel logged every gameupdate

Table 1: Overview over the most relevant driving performance metrics collected during each driving scenarios for every player.

4.1.1 Driving Metrics. We recorded driving-related metrics for each participant and scenario. The metrics, as seen in table 1.

Three additional metrics were calculated afterwards: Initial Time (scenario completion time measured from the first throttle input), Average Speed (calculated over the total completion time), and Crash Occurrence (boolean if any collision occurred during the scenario).

4.1.2 Cognitive Load Assessment. The NASA Task Load Index (NASA-TLX) measures a total of six dimensions of workload. We provided a German and an English version based on the preference of the participant.

These are the six dimensions with the corresponding English questions:

(1) Mental Demand: How mentally demanding was the task?
(2) Physical Demand: How physically demanding was the task?
(3) Temporal Demand: How hurried or rushed was the pace of the task?
(4) Performance: How successful were you in accomplishing what you were asked to do?
(5) Effort: How hard did you have to work to accomplish your level of performance?
(6) Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?

The participants rated each dimension on a 20-point scale from "Very Low" to "Very High".

4.1.3 Eye Tracking Measures. Eye tracking data was analyzed to understand how the visual attention was split between the two screens for the group with both views. The pupil labs neon eye-tracking glasses record a front-facing video and track the fixations of the participants' eyes.

We recorded all 90 driven scenarios and used the recordings of the scenarios belonging to the UAV group for analysis. Out of those 45 scenarios, 5 (no front-facing camera), which means we have a total of 40 eye-tracking recordings of the UAV group for analysis. Every record includes one front-facing camera view and two camera views pointed at the eyeballs of the participants. Then the software of the glasses calculates x and y coordinates for every fixation by calculating an average of all mapped gaze samples within the fixation.

4.1.4 Tele-Driver Confidence. Operator confidence is one of the many factors that play a crucial role in driving behavior. In remote driving or teleoperated setups, low confidence can lead to hesitation, overly cautious maneuvers, or errors, which can increase the risk of accidents. For example, a remote operator may hesitate to make decisions when visibility is limited, resulting in delayed reactions that affect safety and efficiency [16][10].
The integration of a tethered top-down UAV view offers a promising solution. Providing a real-time overhead perspective of the vehicle's surroundings could aid in eliminating blind spots of ground-level cameras [17]. This enhanced viewpoint provides operators with greater situational insight. As a result, drivers could make more informed decisions, reducing anxiety and boosting confidence. Ultimately, this approach could possibly improve driving performance significantly.
To measure driver confidence we used a questionnaire in which Participants could select on a predefined scale, how confident they felt during the driving interaction.

4.2 Qualitative Measures

The qualitative data were collected through two sets of open-ended questions: one directly after the final scenario, and one as part of the final questionnaire referring to all three scenarios. The scenario-specific questions focused on perception and reaction, asking participants: "How did you perceive the situation?" and "How did you handle this driving situation?" In addition, participants rated their perceived level of control on a scale from 1 to 7. This numerical rating served as a starting point for follow-up questions, which encouraged participants to elaborate on why they felt more or less in control and which factors contributed to their assessment. These responses provided deeper insight into participants' awareness of relevant events, their interpretation of risks, and their situational reasoning.

The final questionnaire included more general reflections. Participants were asked: "What did you like?", "What didn't you like?", "When did you use the drone view?" and "Why did you use the drone view in those situations?" These questions were designed to capture strategies, preferences, and the perceived usefulness of different perspectives when navigating challenging environments. In addition, participants were asked how well they were able to orient themselves throughout the scenarios and whether there were aspects they found particularly difficult or unsatisfying. These qualitative responses also helped contextualize the eye tracking data. Gaze recordings showed when and where participants looked while the open-ended answers provided insight into why they used certain views and what they were trying to achieve in those moments. Together, these measures contributed to a broader understanding of how participants perceived, processed, and responded to complex remote driving situations.

5 Results

Participants were asked to self-assess their driving experience. Most rated their driving skills as average (n = 20), while n = 7 reported above-average driving experience, and n = 1 reported poor experience. Two participants did not provide a response.

In terms of previous experience with simulated driving environments (for example, video games or driving simulators), responses were more varied: n = 3 reported poor experience, n = 11 below average, n = 8 average, n = 4 above average and n = 1 excellent. Two participants did not provide an answer.

5.1 Driving Performance

Independent sample t-tests were used to compare continuous variables between groups, while Fisher's exact test or Chi-square tests got used for categorical variables (the crash occurrence) based on the cell frequency. Statistical significance was set at $\alpha = 0.05$. Effect sizes were calculated using Cohen's d. An overview over all data can be seen in table 2.

5.1.1 *Cross-Scenario Performance Analysis.*

Analysis across all three scenarios revealed consistent patterns of significantly different results with UAV view supplementation.

Time-based metrics (total completion time and throttle time) showed an average reduction of 18.1%, with individual reductions ranging from 13.3% to 21.3% across scenarios in favor of the uav group.

Speed-based metrics (average, median, and maximum speeds) showed more substantial differences, with an average of 26.6% higher values and individual improvements ranging from 17.4% to 35.1%.

Scenario 2 (Windy Day) shows the highest overall effects, with the highest average effect size and most significant p-values.

All analyzed completion time and speed metrics across the three scenarios demonstrated statistically significant improvements with UAV view enhancement (all $p < 0.05$). Effect sizes ranged from $d = 0.82$ to $d = 1.04$, with a mean effect size of 0.93.

The strongest individual effects were observed in Scenario 2's throttle time ($p = 0.010$, $d = 1.01$) and average speed ($p = 0.008$, $d = 1.04$), while the smallest but still substantial effect was found in Scenario 1's median speed ($p = 0.035$, $d = 0.82$).

We also analyzed the Time log measurement in order to detect potential limitations relating to low frame rates, as high frame rates are important for smooth visual display and a good user experience.[12]. Results showed no indications of performance issues, as 95% of the time generated frame were close to the monitor refresh rate of 60Hz.

5.2 Cognitive Load

The NASA Task Load Index (NASA-TLX) was conducted to assess subjective workload across six dimensions: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. Cronbach's alpha coefficients indicated acceptable to good internal consistency across both scenarios. For Scenario 1, overall reliability was acceptable ($\alpha = 0.747$,), with good reliability for the control group ($\alpha = 0.784$) and acceptable reliability for the UAV-enhanced condition ($\alpha = 0.697$). Scenario 2 demonstrated good overall reliability ($\alpha = 0.833$), with good reliability maintained in both the control group ($\alpha = 0.855$) and UAV group ($\alpha = 0.809$).

5.2.1 *Overall Workload Assessment.*

Analysis of overall NASA-TLX scores revealed no significant differences between experimental conditions across both scenarios. In Scenario 1 (night fog conditions), participants in the control condition reported similar workload levels ($M = 41.55$, $SD = 16.47$) compared to those with UAV supplementation ($M = 40.22$, $SD = 13.74$),, $p = 0.812$, Cohen's $d = 0.088$. The UAV condition showed a minimal 3.2% reduction in perceived workload.

Similarly, Scenario 2 (windy day with obstacles) showed identical mean workload scores between conditions. Both the control group ($M = 40.83$, $SD = 18.74$) and UAV group ($M = 40.83$, $SD = 14.84$) reported equivalent subjective workload, $p = 1.000$, Cohen's $d = 0.000$.

5.2.2 *Individual Subscore Analysis.*

Detailed analysis of individual NASA-TLX dimensions across both scenarios revealed no statistically significant differences between conditions for any of the six workload components (all $p > 0.05$). Figure 4 shows a visualization of the six measured dimensions with the responses split between both groups and combined from scenarios 1 and 2, although without any significant differences.

5.3 Eye Tracking Analysis

Eye tracking analysis was conducted exclusively for participants in the tethered view condition (front view + UAV perspective) to examine visual attention allocation between the two display areas for

Metric	$Value_{without}$	$\sigma_{without}$	$Value_{with}$	σ_{with}	p	*Cohen's d*
			Scenario 1			
total time	96.72	12.389	83.861	15.378	0.018	0.921
initial time	2.059	1.131	2.581	1.348	0.261	-0.419
total crashes	0.667	1.047	0.4	0.737	0.427	0.295
avg. speed	15.022	1.848	17.631	3.536	0.019	-0.925
			Scenario 2			
total time	82.636	20.125	65.265	14.767	0.012	0.984
initial time	2.042	1.094	1.862	0.824	0.616	0.185
total crashes	1.467	2.386	1.467	1.598	1	0
avg. speed	9.697	2.151	12.239	2.712	0.008	-1.039
			Scenario 3			
total time	49	12.387	39.736	9.883	0.032	0.827
initial time	2.002	0.831	1.966	0.754	0.903	0.045
total crashes	0.0%	N/A	20.0%	N/A	0.224	N/A
avg. speed	7.574	1.524	10.104	3.661	0.023	-0.902

Table 2: Combined Result Overview for all three scenarios for both groups, including a significance t-test and cohen's d

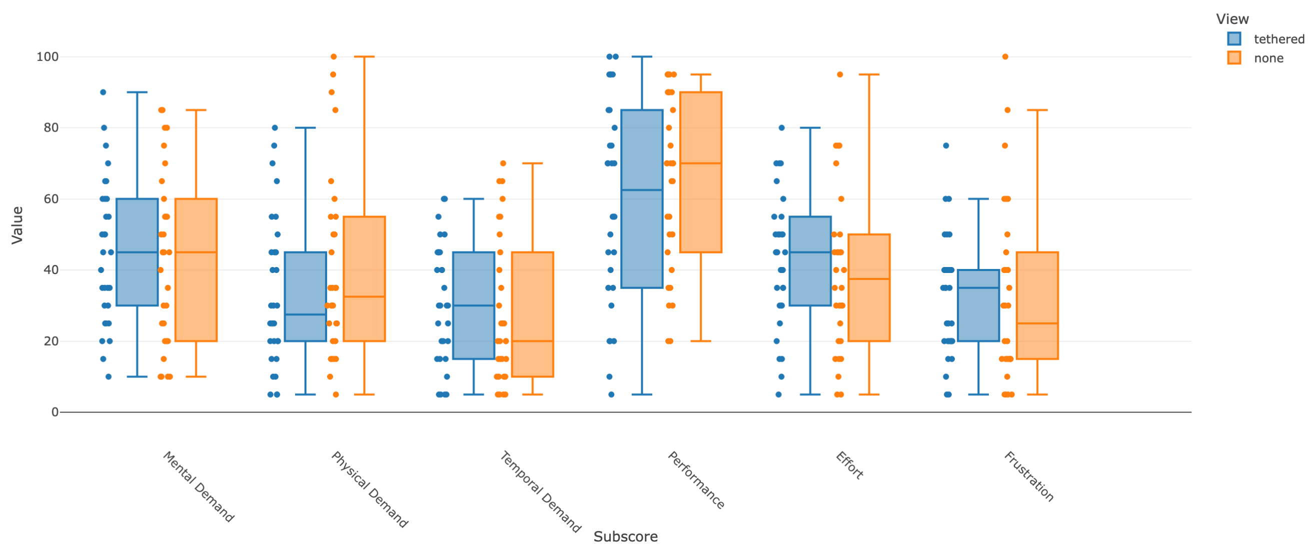

Figure 4: combined NASA-TLX individual subscore comparison between both groups in for scenario one and two

Scenario	$Mean_{Center}$	$Median_{Center}$	SD_{Center}	$Mean_{Right}$	$Mean_{Right}$	SD_{Right}	p
S1	87.902%	92.415%	14.055	19.241%	8.941%	26.939	< 0.001
S2	62.405%	69.922%	32.809	47.595%	48.284%	35.227	0.461
S3	67.691%	75.345%	29.888	40.643%	33.752%	33.752	0.128

Table 3: Comparison of proportional fixation duration in percent for all scenarios and screens

all scenarios. The analysis tool delivered the total fixation duration across two Areas of Interest (AOI), based on the two screens seen in Figure 1.

Total fixation duration. We calculated % values for the split in attention on the screens over the time the scenario was running. An overview of the data can be seen in Table 3. In the first scenario, participants focused significantly more on the center screen (M =

92.42, $SD = 14.06$) than on the right($M = 8.94$, $SD = 26.94$) with $p < 0.001$.

In the second scenario, it looks quite different. Here, the median values are closer to each other between the center screen ($M = 69.92$, $SD = 32.81$) and the screen on the right ($M = 48.28$, $SD = 35.23$) with $p = 0.46$

The third scenario shows similar results as the second one, with the center screen ($M = 75.35$, $SD = 29.89$) being not as dominant in watch time as the right screen ($M = 33.92$, $SD = 33.75$).

Statistical analysis conducted using a one-way ANOVA $F(2, 39) = 36.322,\ p < 0.001,\ \eta^2 = 0.651$) to compare UAV view usage percentages across the three scenarios confirmed these differences were significant.

- Scenario 1 (8.94%) vs Scenario 2 (48.28%): p = 0.0000, d = 3.36 (very large effect)
- Scenario 1 (8.94%) vs Scenario 3 (33.92%): p = 0.0000, d = 2.61 (very large effect)
- Scenario 2 (48.28%) vs Scenario 3 (33.92%): p = 0.0569, d = 0.77 (medium effect)

5.4 Situational Awareness

Situational awareness was assessed through an open-ended survey after the third scenario. The responses revealed a high level of variability in the perception and assessment of the scenarios, with individual differences playing a noticeable role.

The question posed to participants was: "How did you perceive the situation?" While all participants noticed the large number of pedestrians, the sheer volume of people created a sense of uncertainty for some. Participant P11 (without UAV) stated, "The last session was difficult to manage due to the high level of crowding. It felt unsafe and risky, and the narrow field of view added to the stress," while P25 (with UAV) noted, "Due to the large number of pedestrians on the road, it required a high level of attention."

The UAV view was considered helpful by most participants. For example, P5 said, "It was very stressful because I had to pay attention to many people, especially children. The drone view helped in anticipating what might happen. It provided the better view, giving me a much clearer overview of the situation." P12 mentioned, "The UAV view was helpful for orientation and understanding the surroundings. I switched between views regularly." However, there were also participants who rarely used the UAV view. P17 remarked, "It was stressful due to the large number of people. The street was crowded, with people on the sidewalk and children on the road, who were only noticed very late. I used the drone view very rarely."

5.5 Tele-Driver Confidence

To measure driver confidence we used a questionnaire in which Participants could select on a predefined scale from 1-7, how confident they felt during the driving interaction.
This data was collected at the end of our third and final test scenario. Participants were asked the following question: "On a scale of 1-7, how much did you feel that you had everything under control?" This question provides insight into how confident operators felt in their driving ability and the level of control they perceived. The question regarded only the third scenario because it is the only one that includes walking pedestrians and incorporates real threat detection for children crossing the street.
Among all 30 Participants 28 answered this Question. Here are the Answers:

- **Control group (n = 14):** [5, 7, 4, 4, 5, 5, 6, 7, 3, 6, 6, 5, 6, 7]
- **UAV View group (n = 14):** [3, 6, 2, 6, 6, 5, 5, 6, 4, 6, 5, 6, 7, 7]

Group	Mean Confidence	Standard Deviation
Control	5.86	1.21
UAV View	6.00	1.33

Table 4: Descriptive Statistics of Confidence Ratings by Group

To examine whether the addition of a tethered UAV view influenced operator confidence ratings, an independent samples t-test was conducted. The results can be summarized as follows:

- The t-test result was: $t(26) = -0.29$, $p = .77$.
- The calculated effect size was ($d = 0.11$).

5.6 Qualitative Feedback

The qualitative data revealed that participants primarily used the UAV view to estimate distances, navigate obstacles, and orient themselves in complex environments. It was especially valued in situations involving narrow spaces or limited visibility.

Several participants mentioned using the UAV view to better estimate distances and navigate around obstacles. For instance, Participant P1 stated, "I used the UAV view to better navigate around obstacles, as it provided a clearer overview of the environment," while Participant P3 mentioned, "I mainly used the drone view in tight spaces and to better estimate distances, in order to prevent collisions." Participant P10 also noted, "In situations where a complete overview was necessary or when navigating through narrow spaces, I used the drone view to drive more proactively and safely."

The UAV view was also regarded as helpful for orientation, especially in complex scenarios. Participant P8 explained, "I used the view to clearly see where the road goes." Participant P12 highlighted, "I used it the beginning to orient myself in the scene," showing how the UAV view was particularly useful in providing an initial sense, of the surroundings.

Participants also pointed out that the UAV view provide an improved overview and enhanced spatial perception. Participant P5 noted, "You could get more information at a glance," while also recalling how they spotted a woman who was not visible before using the UAV view. P5 also emphasized, "The UAV perspective provided a better overview compared to the default view." Participant P12 shared, "Helpful for orientation and understanding the surroundings." Participant P24 mentioned that the view of the UAV improved their understanding of the vehicle's dimensions, saying, "It was beneficial for a better perception of the vehicle width." Furthermore, P22 pointed out that they analyzed obstacles from another angle when using the UAV view. Participant P19 added, "It gives a better view in blind spots," underlining the advantage of the UAV view in uncovering hidden elements in the environment.

Many participants switched between the views depending on the situation. As Participant P12 explained, "Starting with the UAV view for orientation, then returning to the front view," a sentiment echoed by Participant P26, who said, "I regularly switched between the drone view and the front view." Participant P22 shared, "I used the drone view mainly for orientation and in tight curves or when navigating obstacles to ensure I was correctly positioned. Otherwise, I used the front view when the road was clear." This adaptive approach to using both views demonstrates how participants leveraged the UAV view for situational awareness, precise maneuvering, and risk analysis, while relying on the front view for more straightforward driving situations.

In general, the UAV view was found to be helpful by most participants, and it was used accordingly to improve situational awareness and driving precision. However, there were a few exceptions. Participant P26 stated, "I found the front view overall better, I just looked at the UAV view 1-2 times to get a better overview. I mostly used the front view." Additionally, Participant P17 mentioned, "I used the drone view very rarely – only twice."

6 Discussion

6.1 Driving performance improvements

The results support $H1_1$, showing that UAV view supplementation significantly improves driving performance. This aligns with previous research, where overhead perspectives enhance environmental understanding and navigation efficiency [2] [7].

6.1.1 *Task completion time.*

Participants with UAV supplementation completing tasks faster than the control group might have meaningful implications for emergency response applications, when it's crucial for the remotely controlled vehicle to reach its destination quickly.

Scenario 2 (obstacle course) showed the largest improvement, suggesting that UAV views are most beneficial in complex environments requiring spatial reasoning for obstacle navigation.

These results contradict previous research findings, which demonstrate that secondary tasks increase mental strain and often degrade primary task performance, particularly as task complexity and amount of information increase [11]. Other studies also suggest that additional information sources, such as supplementary camera views, typically increase cognitive load that outweighs potential benefits [2].

However, several methodological differences may explain the different findings between our study and previous research. As previously mentioned, Boker and Lanir's referenced investigations relied on prerecorded videos rather than interactive simulations, which better matches the dynamic decision-making demands of teleoperation. Additionally, our environment allowed participants to selectively use the UAV view when it's needed, rather than viewing both information sources on the same monitor. And the task-based nature of our scenarios may have also altered the cognitive load of the participants by focusing on completing the scenario instead of trying to remember details from the video.

6.1.2 *Crash rates.*

The non significant results regarding crash rates reflect the complex relationship between enhanced situational awareness and safety outcomes. Meteier et al. [14] found that obstacle types and environmental conditions significantly affect takeover performance and collision avoidance. Our results suggest that while UAV views improve navigation efficiency, they may not directly translate to crash reduction across all scenario types.

It is up to future work to evaluate the potential for crashes with a larger test group, as accidents seem to be affected by the condition of the participants. A lack of focus or concentration increases the chance of a crash [4], and as seen in the low p values, crashes seem to occur randomly with a participant count of 15 per group.

The disconnect between improved performance metrics and crash prevention may indicate that scenarios were designed to be challenging enough to produce crashes regardless of viewing conditions.

Design Implications: While UAV views improve operational efficiency, additional safety measures may be needed to translate enhanced awareness into crash prevention. Future implementations should consider collision warning systems complementing aerial views, optimize UAV positioning for specific hazard types, and develop training protocols emphasizing effective aerial perspective use for hazard detection.

6.2 Situational Awareness

Although we are not fully able to reject or support H_2 through non-significant quantitative and qualitative data, we made significant findings using exploration on the usage pattern of the UAV view.

6.2.1 *Eye Tracking and Adaptive View Usage.*

The eye tracking data shows a significant variance in UAV usage patterns between the scenarios:

Minimal Usage in Low-Visibility Conditions: We found reduced utility when visibility limits the perspective benefits. This might relate to the fog conditions, that limited the visibility of objects through the UAV view. In addition to that the scenario contains two long straight road segments, that may have also reduced the need for spatial orientation assistance.

Higher Usage for Obstacle Navigation: Scenario 2 showed the highest UAV utilization in an complex obstacle courses requiring spatial reasoning and path planning. This peak usage also correlated with the largest performance improvements across all metrics.

Selective Usage in Urban Environments: Scenario 3's moderate usage shows strategic usage for locating pedestrians and orientation tasks.

This usage variation suggests operators adaptively allocate visual attention based on task demands.

The results provide some indication that the addition of a UAV view could enhance situational awareness for remote operators, but the findings were not significant enough to fully support hypothesis $H2_1$, which suggested that the UAV view would significantly increase situational awareness. While participants generally reported positive experiences with the UAV view, these effects were not visible in the driving performance.

Several participants noted that the UAV view helped them better perceive their environment and navigate more effectively. For example, Participant P26 remarked, "At the bus stop, the drone view made it easier to spot the children," highlighting how the UAV perspective improved their awareness of pedestrians in complex environments. Participant P22 also stated, "I used the drone view when I needed orientation and to view obstacles from a different perspective, helping me avoid accidents," suggesting that the UAV view was useful for understanding the surroundings and avoiding potential hazards.

In contrast, participants without the UAV view faced challenges in assessing distances and obstacles. Participant P11 explained, "Sometimes the view felt off, and I thought I had hit something, especially in Scenario 2 when driving past a stationary vehicle in the construction zone." demonstrating how the limited view in the front view led to uncertainties. Similarly, Participant P16 mentioned, "It was hard to estimate the size of the vehicle," and Participant P18 stated, "The path was sometimes only visible too late, which made orientation difficult," further supporting the notion that the absence of an overhead view impaired situational awareness.

While subjective feedback on the UAV view was largely positive, with many participants noting its helpfulness in providing a clearer overview and improving decision-making, the lack of significant improvement in situational awareness and its impact suggests that other factors may be at play. The absence of a clear and consistent effect could be attributed to the relatively small sample size (N=30), which might not have been sufficient to detect statistically significant differences in situational awareness between the UAV and non-UAV conditions.

6.3 Cognitive Load

NASA-TLX results do not provide sufficient evidence to reject $H3_0$ for any of the scenarios. The small effect sizes indicate that even an undetected effect would be practically negligible.

It is noteworthy that the absence of significant subjective workload differences occurred along with significant objective improvements in the driving performance metrics. This contrast suggests that UAV supplementation potentially improved operational efficiency without imposing an additional significant cognitive burden on remote operators.

This challenges assumptions in multi-perspective interface research, which proved secondary tasks to increase mental strain and degrade primary performance, especially with increasing complexity [6]. Our findings suggest that when additional visual information directly supports the primary task, it may not impose typical multitasking cognitive penalties.

Several factors may explain this unexpected pattern. First, the UAV view may have reduced uncertainty and ambiguity in spatial reasoning tasks, potentially offsetting any additional cognitive demands from processing multiple information sources. Secondly, participants could have developed adaptive attention allocation strategies, utilizing the UAV view selectively when it benefits them the most, rather than continuously switching between both displays.

6.4 Tele-Driver Confidence

The independent samples *t*-test showed that there was no statistically significant difference in confidence levels between the groups. The effect size calculated was very small ($d = 0.11$). In particular, the confidence that participants reported was not different between the “UAV View” and “Control” groups, $t(26) = -0.29, p = 0.77$. Even though the group with the UAV view showed a slightly higher average confidence rating, this difference was very small and it was not statistically significant. The addition of a top-down camera view did not significantly influence the confidence levels of the drivers in this scenario. Hence, we have to go with ($\mathbf{H5_0}$), which is the null hypothesis for this test, meaning there is no evidence that a difference in confidence ratings between the groups is found. More research with bigger sample sizes might be needed to investigate possible trends or effects in a more robust way.

Performance-Usage Correlation. Notably, scenarios with higher UAV usage also showed greater performance improvements, suggesting operators effectively recognized when aerial perspectives offered maximum operational benefit. This adaptive behavior indicates potential for training protocols emphasizing scenario-specific usage strategies.

Design Implications: Interfaces should support dynamic attention allocation between perspectives, making UAV views easily accessible without forcing attention when not needed. Different viewing modes may be optimized for various scenario types, and training should help operators recognize when aerial perspectives offer the greatest benefit.

7 Limitations

First up, it is important to mention the non-negligible differences between the simulator and the real world, as the steering, braking, and acceleration did not replicate the exact feel of a real vehicle, which could have led to an adjustment period for participants.

The Logitech G29 was noticeably smaller than that of a typical car steering wheel.

The absence of both interior and exterior mirrors could have impacted the participants situational awareness during the task.

The study was conducted with a sample size of N=30. A larger sample size would have allowed for more in-depth insights and a broader range of data.

Additionally, all participants were under the age of 35. Including a more diverse age range in future studies could provide valuable insights into how different age groups approach the task and interact with the UAV view.

Next up we only tested one UAV configuration. Other configurations, viewing angles, fovs, distances, and follow patterns could lead to different results.

8 Future Work

The research findings open up a few promising ways for more research on how extra UAV views help in teleoperated driving interventions. While the UAV view did improve task completion time a lot without adding any noticeable cognitive load, there are still some questions left about its wider effects and best ways to use it. One key aspect to look into next, is testing how UAV add-ons work in busy, changing environments. Our tests tried to cover a range of different environments but did not include a high traffic scenario like one would expect in big cities. Looking at how UAV support might help in these situations could show if performance boosts change and if awareness benefits get bigger in different cases.
Also the mixed results on crash rates need further investigation. UAV views made navigation faster, but they did not always cut down on collisions. This might be because of the scenario difficulty and differences between participants. Further studies should try mixing UAV views with safety tools like collision alerts or path

predictions, to see if they improve awareness and gain real safety wins.

The eye-tracking data showed that people used the UAV view differently based on the scenario, pointing to how operators adapt. Future work could dig deeper into how the interface setup affects where people focus and what they prioritize. For instance investigating various ways to add UAV views such as picture-in-picture split-screen or turning it on when needed, might help find the right balance for awareness and mental workload.

Moreover, even though tests showed no big jump in cognitive load, people's feedback said UAV views were helpful in spots. This means we need follow-up studies with bigger, more varied groups and better ways to measure workload, like using heart rate changes or EEG scans, to catch finer details. Finally confidence ratings did not change between groups, suggesting that UAV help does not boost how capable people feel. While it may not directly affect perceived self-efficacy. Future research could explore training interventions designed to familiarize operators with aerial views and assess whether increased proficiency leads to greater confidence and improved decision-making under pressure.

9 Conclusion

This study explored how a supplementary UAV perspective influences remote driving. The results show that UAV support can significantly improve driving performance, particularly in tasks requiring spatial reasoning and obstacle navigation. Participants completed scenarios more efficiently without reporting higher cognitive workload, indicating that the aerial view provided relevant information without overloading the operator. Eye tracking data further revealed that participants used the UAV view selectively, depending on the complexity of the situation. However, these performance improvements did not consistently translate into measurable gains in situational awareness or safety outcomes. Although many participants described the UAV perspective as helpful for orientation and spatial understanding, crash rates and self-reported awareness did not differ significantly between groups. Confidence ratings were similarly unaffected. These findings highlight the value of UAV views as a task-relevant support for navigation without imposing additional cognitive demand. At the same time, they underline the importance of interface design and training to ensure that added perspectives are used effectively. To maximize the potential of aerial support, future work should explore adaptive interface designs, integrate additional safety cues (e.g. collision warnings), and evaluate performance under real-world conditions with more diverse user groups. Overall, UAV-enhanced teleoperation shows strong potential to increase efficiency and adaptability in remote driving – especially when the interface allows flexible, context-sensitive use.

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