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EFFECTS OF AUGMENTED SITUATIONAL AWARENESS ON DRIVER TRUST IN SEMI-AUTONOMOUS VEHICLE OPERATION

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ABSTRACT

Although autonomy has the potential to help military drivers travel safely while performing other tasks, many drivers refuse to rely on the technology. Military drivers sometimes fail to leverage a vehicle's autonomy because of a lack of trust. To address this issue, the current study examines whether augmenting the driver's situational awareness will promote their trust in the autonomy. Results of this study are expected to provide new insights into promoting trust and acceptance of autonomy in military settings.

INTRODUCTION

Autonomous and semi-autonomous vehicles have the potential to help drivers successfully and safely complete many military missions while providing the drivers with the flexibility to address other pressing issues not possible while actively driving [12]. Following the SAE definition (SAE J3016), driving automation systems are those that "perform part or all of the dynamic driving task on a sustained basis", ranging in level from no driving automation (level 0) to full driving automation (level 5). The "dynamic driving task" includes things such as sensing, navigation, steering, and speed control. Unfortunately, drivers have failed to fully leverage a vehicle's autonomy because of a lack of trust in the vehicle's autonomy [5]. Trust in a vehicle's autonomy allows the driver to handle the uncertainty and risk associated with giving driving control to the vehicle's autonomy [3]. Generally, trust is one of the most vital components in understanding how to promote successful teaming between humans and robots [6]. Specifically, drivers need to be comfortable relying on the vehicle's autonomy in order to make better decisions regarding whether or not to employ it [3].

Trust in automation has been studied in the past, primarily in the domains of aviation and production processes. However, less is known about trust in automated vehicles specifically.

Previously developed methods for evaluating trust in automation provide a good starting place for considering this specific domain, but there are three major shortcomings. Firstly, models of human trust in autonomy typically only consider the human's trust in the autonomy [1]. Yet, trust between two agents is reciprocal and mutual [13], especially given the highly sophisticated sensing, decision-making, and acting functions that autonomous vehicles are expected to have in the future. Second, current models of trust between a driver and the vehicle's autonomy are neither contextualized nor personalized [8]. Finally, the degree to which mutual trust between the driver and the vehicle's autonomy exists and changes as a function of how expectations are met. Prior research has recognized the importance of human expectations of automation in determining the trust humans have in automation [3]. Less is known about what expectations drivers have for their vehicle's autonomy in general, and no known research has been conducted that has examined the expectations a vehicle's autonomy should have for its driver.

This pilot study is positioned to lay the groundwork for developing sophisticated and robust models of mutual trust between driver and semi-autonomous vehicle. The ultimate goal of the larger project is to develop methods to predict when a driver is likely to seize control from or relinquish control to the vehicle and to predict when the vehicle should relinquish control to or seize control from the driver. The purpose of this study is to begin this investigation by examining how a driver's trust in their semi-autonomous vehicle is impacted when the driver's situational awareness is purposefully augmented by the vehicle. The hypothesis of this study is that by augmenting the driver's situational awareness using effective communication, the driver will demonstrate more trust in the vehicle's autonomous capabilities.

METHOD

This study is designed to evaluate driver trust in semi-autonomous driving when the driver's situational awareness is purposefully augmented by the vehicle. The study employs an experimental design using three different conditions of communication content from the vehicle. These conditions will be counterbalanced using a Latin Square design to minimize learning and ordering effects. Participants will be asked to operate a simulated vehicle while attending to a visually demanding non-driving task. Trust will be evaluated from survey responses and analysis of physiological data.

Participants

Thirty-six licensed drivers will be recruited from the Ann Arbor, MI area to participate in a driving simulator experiment. All participants are to have normal or corrected-to-normal color vision as well as auditory acuity. Participants will be compensated $10 for participation and will be eligible to receive a cash bonus based on their performance in the experiment.

Tasks

Participants will be given the task of operating a simulated semi-autonomous vehicle while also attending to a visually-engaging non-driving task. The simulated vehicle will be equipped with lane-keeping, speed-maintenance, and automatic emergency braking capabilities. The virtual driving scenario will be a standard two-lane highway with a hard shoulder (see Figure 1). Participants will be told that the simulated vehicle is capable of driving itself, but that, given the highway speeds, it might not be able to maneuver around a stopped obstacle on the roadway. In these circumstances, participants will need to take control of the vehicle by turning the steering wheel or applying the brake. Failure to do so will result in the simulated vehicle automatically emergency braking.

Figure 1: Simulated driving environment.

The non-driving task (see Figure 2) is a modified version of the Surrogate Reference Task (SuRT; [9]). The SuRT resembles a target recognition task, in which participants are required to identify a target item (the letter Q in this study) from amongst a field of distractors (the letter O) and manually select it on a touchscreen located to the right of the participant.

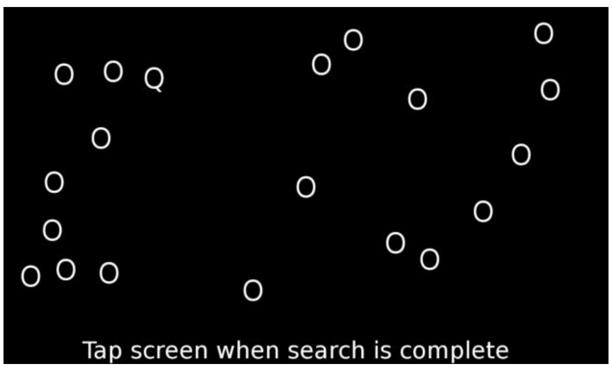

Figure 2: Non-driving task.

Apparatus

The study will be conducted in a static driving simulator with three visual channels. The simulated vehicle is equipped with lane-keeping, speed-maintenance, and emergency braking capabilities. Autonomous Navigation Virtual Environment Laboratory (ANVEL) is used to create the virtual environment and implement the semi-autonomous driving behavior. PEBL ([10]) is used to create the non-driving task. The task itself will be administered on a touchscreen to the right of the participant where a vehicle's center console would be in an actual vehicle. A head-mounted eye-tracker will be used to collect participant gaze behavior during the study. This device captures video of the wearer's field of view and of the wearer's right eye. The manufacturer's software is used to extract fixation, pupil diameter, and blink rate for analysis. Heart beat rate and heart rate variability will also be collected during the study.

Figure 3: Experiment setup.

Independent Variables

This study employs a one-factor within subjects design. The single independent variable in this experiment is the auditory message the vehicle supplies the driver. Each participant will complete the driving task under three conditions of this messaging. These conditions will be counterbalanced using a Latin Square design to minimize learning and ordering effects. These three conditions are tabulated below. During each driving session, the participant will encounter four stopped vehicles on the roadway. Only a subset of these stopped vehicles will be located in the same lane as the driven vehicle, and thus only these stopped vehicles will require driver intervention to prevent a collision.

Condition	Auditory Message	Circumstance
C1	None	
C2	"Stopped vehicle ahead"	For all stopped vehicles
C3	"Stopped vehicle ahead" followed by	For all stopped vehicles
	"No action needed"	For stopped vehicles in the other lane
	OR	
	"Take control now"	For stopped vehicles in the same lane

Table 1: Experimental conditions.

Dependent Variables

The dependent variables fall into four categories:

1. *Eye-tracking data:* 1a, monitoring frequency, 1b. monitoring ratio, 1c. blink rate, and 1d. pupil dilation will be measured with an eye-tracker headset. "Monitoring" refers to driver vigilance of the vehicle's behavior, i.e. gazing at the driving scene. "Monitoring frequency" refers to the number of glances (visual fixations longer than 120 ms) at the driving scene over a fixed period of time. "Monitoring ratio" refers to the ratio of time spent looking at the driving scene to the time spent looking elsewhere. The eye-tracking metrics chosen for this study are derived from those employed in [7], a similar study in which researchers found a relationship between driver monitoring behavior and automation trust.
2. *Heart rate data:* 2a. heart beat rate and 2b heart rate variability will be measured with a heart rate monitor.
3. *Simulation data:* simulated vehicle state (3a. position, 3b. heading, 3c. velocity, 3d. yaw rate, 3e. acceleration), 3f. proximity to obstacles, participant take-over behavior (3g. steering input, 3h. pedal input), and 3i. participant non-driving task engagement will be collected during the experiment.
4. *Survey responses:* participants will respond to surveys after each driving session (these surveys are described in "Procedure")

Procedure

First, participants will complete a consent form to participate in the study. Next, they will complete a pre-experiment survey consisting of three components. The first component consists of questions about participant personal information, as well as experience using driving aids, such as ACC adaptive cruise control and automatic emergency braking. The second component consists of the Self-Assessment Manikin [2] to determine mood before participating in the experiment. The third component consists of questions to determine each participant's propensity to trust in automation, derived from [14].

After completing these three components of the survey, the experimenter will explain the details of the overall experimental task. Participants will complete a brief training session in order to introduce them to the vehicle controls and the non-driving task. Following training, the eye-tracker and heart rate monitor will be fitted and calibrated. Participants will then complete three test sessions, one corresponding to each of the communication conditions (described above). After each session, participants will complete the post-condition survey consisting of three components. The first component is the Situation Awareness Rating Technique (SART; [15]) to determine the extent to which the participant's situational awareness is modulated under the different test conditions. The second component consists of questions about trust in automation, derived from [11] and adapted to suit this particular study. The last component is the NASA TLX to determine participant workload. All surveys will be administered electronically.

Each experiment will last approximately 90 minutes.

EXPECTED RESULTS

Subject testing is to be conducted in the coming weeks. We posit the following hypotheses:

H1. As we move from C1 to C3, self-reported trust will increase.

H2. As we move from C1 to C3, monitoring frequency will decrease.

H3. As we move from C1 to C3, monitoring ratio will decrease

H4. As we move from C1 to C3, situational awareness will increase

H5. As we move from C1 to C3, non-driving task performance will increase (i.e. frequency of task completion and percentage of correct responses will increase)

H6. As we proceed from C1 to C3, driver take-over behavior will become more controlled (i.e. rate of deceleration and rate of steering input angle will decrease)

Should the hypotheses be confirmed, the methodology investigated here should allow for future work in characterizing compliance as a function of SA support, as well as driver behavior in the absence of that support.

DISCUSSION

Overall, the results of this study should contribute to the literature on trust in AV in the following ways. First, the role of SA will be considered in the context of trust in AVs. This study should demonstrate the importance of situational awareness in promoting trust in AVs. We expect to see trust increase as SA is increased (H1). This would provide evidence that a lack of awareness is a major barrier to trusting AVs. Two, our results are expected to show that the ability of drivers to understand what actions are required of them prior to taking control is vital to encouraging effective use of autonomy. We expect that status updates in the form of C2 and C3 are important but that projection (C3) would be the key to encouraging trust and ultimately use of autonomy. Projection, the third level of SA in Mica Endsley's model of SA [4], "provides the knowledge (and time) necessary to decide on the most favorable course of action to meet one's objectives." However, if we found no relationship between SA and trust this may provide evidence that SA is not a major factor in promoting trust in AVs. Trust in AVs might instead be primarily driven by factors other than SA. We may also find that there are no differences between C2 and C3. This would indicate that status updates are sufficient to promote trust and that projection adds little if any value. This may be important because projection may require more computational power in AVs than simple updates. There would be no need to use additional computation power for projection if it added little value.

Second, this study contributes to the literature by explaining the relationship between trust as a belief (measured by self-report) and trusting behaviors (measured by frequency in monitoring). We expect more trust in the vehicle's autonomy, due to increased SA, to lead to less monitoring of the vehicle's action. Less monitoring should free up cognitive effort which allows the driver to focus more on their secondary task. This reduction in monitoring would be vital to achieving the expected benefits associated with the use of autonomy. However, increases in trust that are not accompanied by less frequent monitoring may be due to several things. One, measures of self-reported trust may not correspond with trusting behaviors, since the self-reported measures may not be good indicators of actual trusting behaviors. Second, another explanation is that we may need to begin to re-think the value of trust in this context. In other words, if trust does not lead to less monitoring and does not free up any cognitive effort, it may not provide the benefits we hope to achieve.

In summary, we expect this study to lead to a better understanding of the importance of trust in

AVs. We see many potential avenues for future research going forward. Future studies will continue to lay the groundwork for developing sophisticated and robust models of mutual trust between the driver and semi-autonomous vehicles. This, in turn, will allow us to predict the driver's actions regarding driving control and to better determine how the vehicle should act or react to the driver regarding control.

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DISCLAIMER

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