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Dynamic Task Allocation and Understanding of Situation Awareness Under Different Levels of Autonomy in Closed-Hatch Military Vehicles

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ABSTRACT

There is a need to better understand how operators and autonomous vehicle control systems can work together in order to provide the best-case scenario for utilization of autonomous capabilities in military missions to reduce crew sizes and thus reduce labor costs. The goal of this research is to determine how different levels of autonomous capabilities in vehicles affect the operator's situational awareness, cognitive load, and ability to respond to road events while also responding to other auditory and visual tasks. Understanding these interactions is a crucial step to eventually determining the best way to allocate tasks to crew members in missions where crew size has been reduced due to the utilization of autonomous vehicles.

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1. INTRODUCTION

Autonomous vehicles are at the forefront of current technological advancements, and as this new technology becomes more widely accepted and commercially available, it is becoming a part of many proposed solutions to current problems and improvements to current systems. One such improvement is in the area of military missions. Since autonomous systems take at least part of the work out of the driving task, it is logical that the addition of autonomous driving technology to military missions could free crew members to attend more to other tasks and thus reduce the overall manpower necessary for mission completion. Due to the potentially unpredictable and complex nature of these missions paired with the current capabilities of autonomous systems, properly implementing such a technology is more complicated than simply eliminating the driver and leaving that task solely to the autonomous vehicle. It is highly likely for situations to be encountered in a mission environment that would necessitate intervention in the driving task by one of the crew members. This leads to a need to determine how to best balance the driving task with other mission tasks in order to reduce crew size while remaining capable of performing all tasks including necessary monitoring of the driving task. The first step in arriving at a solution to this problem is understanding the interaction between humans and autonomous vehicles at different levels of autonomous capability including the humans' situational awareness, cognitive load, and ability to respond to driving events as well as other mission-related tasks.

1.1. Related Work

The idea of augmenting crew size by the use of autonomous vehicles has previously been explored in a study by Anderson et al. [1] who investigated techniques for achieving success with a reduced crew. Among these techniques were strategies for more successful reallocation of tasks, which focused on increasing crew communication and teamwork, eliminating tasks via automation, making tasks easier, and providing better resources for task completion. While these are all important concepts, it is necessary to also consider which reallocated tasks should go to which crew member. Due to the intensity of tasks and the unpredictability of missions, any static allocation of splitting the remaining tasks is not necessarily optimal at any given time. It would increase overall performance to be able to determine which crew member should perform individual tasks without the need for the crew members to decide for themselves after taking time to communicate with one another.

The relationship between situational awareness and cognitive load in mission tasks was investigated in a study by Hollands and Spivak [2] that varied the presentation rate and presentation method of task commands. This study measured situational awareness by having participants give a report of the location of all enemies at varied points in the study while activities ceased according to SAGAT guidelines [3,4]. Cognitive load was measured using NASA-TLX [5,6] and performance was assessed on a Detection Response Task (DRT) [2]. The study found that higher rates of task commands increased cognitive load and decreased situational awareness. Additionally, visual commands increased cognitive load and decreased situational awareness more so than auditory commands. Since these command types are both common in real mission scenarios and will likely differ in their effects on situational awareness and cognitive load, it is important to investigate both when trying to create optimal task allocation.

In a study on the effects of situation awareness on driver trust of partially autonomous vehicles [7,8], participants operated a partially autonomous vehicle while engaging in a secondary task. This study was done in a static driving simulator with participants having to respond to secondary tasks on a touch screen. The simulator consisted of an adjustable seat, steering wheel, accelerator, and brake pedal situated in front of three screens that were angled to slightly wrap around to show front and side views of a relatively low fidelity video driving simulation. The only variable that was manipulated in the study was whether or not the participant was given a prompt to increase their situational awareness, and then it measured situation awareness, cognitive load, and participant reported trust in each case. Along with its findings about trust, the study showed that at higher level of situational awareness, secondary task performance was improved [8]. Due to the similar structure of this study, it is particularly informative to take note their measurements of situational awareness and cognitive load which were the Situation Awareness Rating Technique (SART) [9], and NASA-TLX [5,6] respectively.

Another metric that has been used for situational awareness in partially autonomous driving is the driving behavior itself [10,11] because situational awareness can be inferred by the success of task completion or the behavior to initiate intervention [11]. A study on how situational awareness differs in different autonomy conditions after different periods of autonomous control before "handoff" used this method for situation awareness evaluation [10]. This study was performed in a driving simulator, and participants were alerted by the automation system when they needed to take over rather than determining critical events for themselves. The simulator was a high-fidelity simulator that used a full car body and a smooth, wrap around screen to create the environment.

Driving has been simulated in virtual reality by Brown et al. [12] in a study investigating how human operators of vehicles with no autonomy interact with known autonomous vehicles while driving. The study utilized VR to create an environment that was more immersive and detailed than what is possible with many driving simulation systems while using a physical steering wheel, accelerator, and brake pedal as controllers to optimize the realism of operating the virtual vehicle. This methodology is useful because it gives the ability to measure movements of the physical controls which should already be commonplace to all participants who are licensed drivers. The combination of VR and physical pedals and steering heightens realism and immersion. This is the optimal choice for creating a realistic closed-hatch vehicle environment because most driving simulators are based around common road vehicles with no ability to create a closed environment.

2. EXPERIMENT DESIGN

In order to provide an immersive experience, this experiment utilizes a virtual reality (VR) approach. As seen in figure 1, the VR environment will consist of the interior of a closed-hatch military vehicle with a steering mechanism and two screens, one showing a view outside the vehicle with the other showing a communications screen where visual commands will be received.

The steering mechanism will correspond to a physical steering device that will be mounted in front of the participant to be used as a controller along with physical acceleration and brake pedals positioned and programmed to maximize realism of vehicle operation.

The study will be a between-subjects design with one independent variable for autonomy condition. Measured dependent variables will include situational awareness, cognitive load, driving task performance, and secondary task performance. The expected sample size is 125 participants.

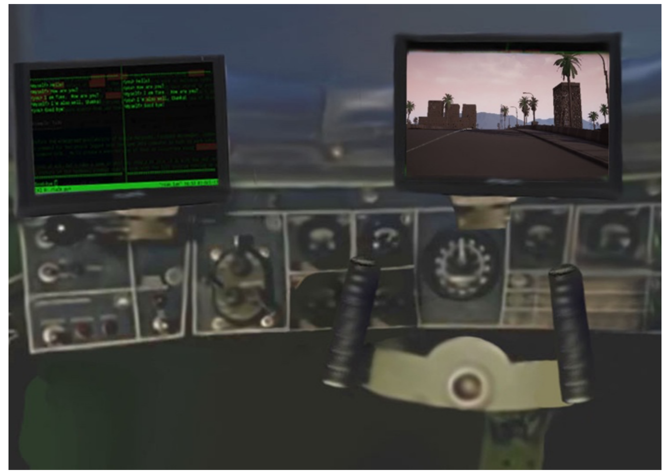

Figure 1: Sample view of the virtual reality environment

2.1. Tasks

During the study, participants will be responsible for performing all or part of the driving task depending on the autonomy condition to which they are assigned. There are five such conditions each adding to the autonomous abilities of the previous condition. These conditions are shown in table 1.

Condition	Autonomous Vehicle Abilities
1	No autonomy
2	Longitudinal control (speed)
3	Condition 2 + lateral control (lane keeping)
4	Condition 3 + automated turning at intersections
5	Condition 4 + obstacle detection and obstacle avoidance

Table 1: Autonomy conditions.

The first condition is the control condition in which the vehicle has no autonomous abilities. Condition 2 adds longitudinal control (speed).

Condition 3 adds lateral control (lane keeping). Condition 4 adds automated turning at intersections, and Condition 5 adds obstacle detection and obstacle avoidance.

Regardless of autonomy condition, road events will occur that go beyond the abilities of the vehicle's autonomy and require intervention by the participant. Such events will be selected from the following: a pedestrian running into the road, a hostile pedestrian with a weapon, an animal running into the road, large items falling off of a vehicle, and debris blowing into the road. An example of a road hazard as it would be seen on the outside view screen in the VR environment is shown in figure 2.

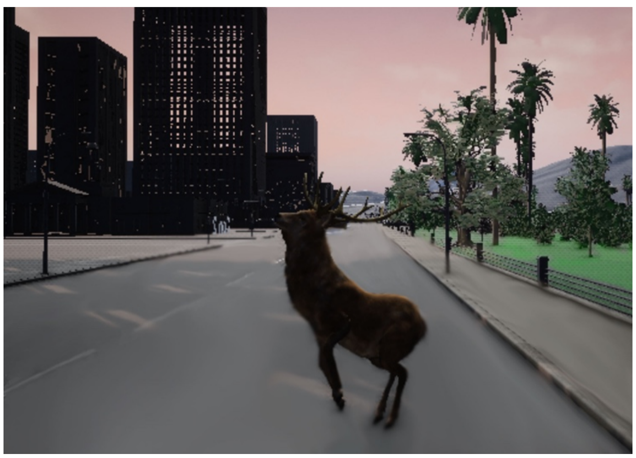

Figure 2: An example road event requiring intervention.

In addition to the driving task, participants will respond to secondary tasks that will be presented to them as both auditory and visual commands. Audio commands will be given over the audio in the VR headset, and visual commands will be given on the communications screen in the VR environment. Such commands will require simple, verbal communications of information displayed within the vehicle such as "Report your fuel level."

2.2. Procedure

Participants will first be introduced to the VR headset and controls that they will be using and will be screened for simulator sickness susceptibility using the Simulator Sickness Questionnaire (SSQ) [13]. Approved, consenting participants will then take part in a three-minute familiarization session where a researcher will guide them through operating the vehicle at their assigned autonomy condition and responding to secondary task commands.

After their familiarization with the system, participants will complete a fifteen-minute test session where they will be operating the vehicle at one of the five previously described autonomy conditions. During the session, they will receive a secondary task command either visually or auditorily once every thirty seconds. The driving task will involve normal conditions except for four road events that will happen at predetermined times of three minutes, six minutes, nine minutes, and twelve minutes into the study. Participants' reactions to these events will be monitored by recording their movements of the steering mechanism, accelerator, and brake pedal. At two random points during the study, the simulation will be paused for participants to respond to questions about their environment and situation to measure situational awareness based on the Situation Awareness Global Assessment Technique (SAGAT) guidelines [3,4]. Physiological measures of heart rate, heart rate variability, and respiration rate will also be collected to determine participants' level of arousal and stress while operating the virtual reality vehicle and responding to the secondary task commands. After completion of the test drive, participants will respond to questionnaires that will be used to further evaluate their situational awareness and cognitive load using the Situation Awareness Rating Technique (SART) and the [9] NASA Task Load Index (NASA-TLX) [5,6].

2.3. Evaluation

The dependent variables that will be evaluated for each autonomy condition include situational awareness, cognitive load, response to road events, and accuracy of secondary task completion. The metrics used to determine situational awareness will be the SART questionnaire given after the study as well as the SAGAT-based questions given during the study. These questions will be formulated in such a way to determine the participants' mission awareness, spatial awareness, time awareness, and vehicle awareness on the three different levels of situation awareness defined by Endsley as level 1: perception, level 2: comprehension, and level 3: prediction [3,4]. Cognitive load will be measured by the NASA-TLX questionnaire that allows participants to respond to the intensity of their workload in terms of mental demand, physical demand, temporal demand, performance, effort, and frustration by indicating their rating of each in a twenty-one-point scale. [5,6] Additionally, cognitive load will be evaluated using the Cognitive Task Load Model developed by Neernix et al. [14] as well as by the participants' stress and arousal as indicated by the physiological measures of heart rate, heart rate variability, and respiration rate.

3. Future Work

After this study to examine how situational awareness and task performance differ in different autonomy conditions, a second study will be done that also varies the rate of secondary task commands in addition to looking at different autonomy conditions. Varying the rate of secondary tasks will reveal the maximum level of cognitive load where successful completion of all tasks can still be achieved. Together with the results of the current study, this will inform a definition of situational awareness, cognitive load, and task performance of vehicle operators as a function of different levels of vehicle autonomy. What is learned from the results of these two studies together will then be used to develop a system to dynamically allocate secondary tasks to optimize performance based on predicted situational awareness and cognitive load.

4. Discussion

This research addresses the effects of automation on vehicle crew members' primary and secondary task performance. This will be crucial information moving forward with efforts to consolidate three-person teams into two-person teams through the addition of autonomous vehicle capabilities giving operators the ability to focus on tasks in addition to driving. The military has a particular interest in how automated driving systems may allow a vehicle operator to address secondary tasks. This project will investigate how such a system will affect the operator's ability to monitor the primary driving task and respond if human intervention is required. Improved understanding of how automation and increased secondary tasking affect operator performance will lead to improved system designs that support effective management of crew member cognitive resources and tasks. Effective task allocation will be critical to efforts to reduce the number of crew members using automation.

Previous studies have investigated task allocation after crew reduction, the relationship of situational awareness and cognitive load, and the relationship of situational awareness and automation, but the question of how task performance, situational awareness, and cognitive load interact with the particular level of autonomous ability of a vehicle has yet to be answered. The answer to this question will be essential to optimizing the utilization of autonomous vehicles in military missions.

1. REFERENCES

[1]E. Anderson, J. Bryant, V. Paul, A. Reid, and J. Schrader, "Use of Crew Augmentation Techniques to Reduce Combat Crew Size," Proc. 2018 NDIA Ground Vehicle Systems Engineering and Technology Symposium (Novi, MI, August 7-9, 2018).

[2]J. G. Hollands and T. Spivak, "Cognitive Load and Situation Awareness for Soldiers: Effects of Message Presentation Rate and Sensory

Modality", Human Factors, vol 61, issue 5, pages 763-773, 2019.

[3]M. R. Endsley, D. J. Garland, and Others, "Theoretical underpinnings of situation awareness: A critical review," Situation awareness analysis and measurement, vol. 1, p. 24, 2000.

[4]M. R. Endsley, "Measurement of Situation Awareness in Dynamic Systems," Hum. Factors, vol. 37, no. 1, pp. 65–84, Mar. 1995.

[5]S. G. Hart and L. E. Staveland, "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research," in Advances in Psychology, vol. 52, P. A. Hancock and N. Meshkati, Eds. North-Holland, 1988, pp. 139–183.

[6]S. G. Hart, "Nasa-Task Load Index (NASA-TLX); 20 Years Later," Proc. Hum. Fact. Ergon. Soc. Annu. Meet., vol. 50, no. 9, pp. 904–908, Oct. 2006.

[7]L. Peterson, D. Tilbury, L. Robert, and X. J. Yang, "Effects of Augmented Situational Awareness on Driver Trust in Simi-Autonomous Vehicle Operation," Proc. 2017 NDIA Ground Vehicle Systems Engineering and Technology Symposium (Novi, MI, August 8-12, 2017).

[8]L. Peterson, L. Robert, X. J. Yang, and D. Tilbury, "Situational Awareness, Driver's Trust in Automated Driving Systems and Secondary Task Performance," SAE Int. J. of CAV, vol 2, issue 2, 2019.

[9]R. M. Taylor, "Situational awareness rating technique (SART): The development of a tool for aircrew systems design," in Situational Awareness, Routledge, 2017, pp. 111–128.

[10]D. Miller, A. Sun, and W. Ju, "Situation Awareness With Different Levels of Automation," Proc. 2014 IEEE International Conference on Systems, Man, and Cybernetics, (San Diego, CA, October 5-8, 2014).

[11]C. A. Bolstad, H. M. Cuevas, J. Wang-Costello, M. R. Endsley, "Measurement of Situation Awareness for Automobile Technologies of the Future," SAE International, 2009.

[12]B. Brown, D. Park, B. Sheehan, S. Shikoff, J. Solomon, J. Yang, and I. Kim, "Assessment of Human Driver Safety at Dilemma Zones with Automated Vehicles through a Virtual Reality Environment," Proc. 2018 IEEE Systems and Information Engineering Design Symposium (Charlottesville, VA, April 27, 2018)

[13]R. S. Kennedy, N. E. Lane, K. S, Berbaum, and M. G. Lilienthal, "Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness," International Journal of Aviation Psychology, vol 3, issue 3, 1993, pp. 203-220.

[14]M. A. Neerincx, "Cognitive task load design: model, methods and examples," Handbook of cognitive task design, pp. 283–305, 2003.