Visual and Auditory Displays of Automation Uncertainty

Zoe M. Becerra
Georgia Institute of Technology
School of Psychology
zbecerra3@gatech.edu

Brittany E. Noah
Georgia Institute of Technology
School of Psychology
brittany.noah@gatech.edu

Bruce N. Walker
Georgia Institute of Technology
School of Psychology and School of Interactive Computing
bruce.walker@psych.gatech.edu

ABSTRACT

Automation features, such as adaptive cruise control and automated lane keeping, are quickly being added to all manner of vehicles. Displays about the behaviors, capabilities, and uncertainty of the automation system are necessary to keep the driver informed about the vehicle and its automation. Auditory displays of automation uncertainty can provide the driver with critical information, without taking visual attention away from the driving task. To ensure that these displays are providing information in a way that is effective for drivers, they must be evaluated for usability. Current and future implementations of these displays, and research to evaluate performance of drivers, is discussed.

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CCS CONCEPTS

• Human-centered computing~Usability testing • Human-centered computing~Auditory feedback

KEYWORDS

Automated Vehicles; Auditory Displays; Automation Uncertainty; Displays; Display Evaluation; Usability; Trust; Driving

INTRODUCTION

With the recent increase in automation in commercially available vehicles, there has also been a call for more transparency in automated systems [11]. Academic researchers and car manufacturers have been exploring ways to present necessary information to drivers. Many times, what is addressed are takeover requests, as outlined by the SAE definition for conditional automation (Level 3) [17]. There is, however, a growing body of research supporting presentation of *automation uncertainty* [2,9,10,18]. Displays of uncertainty level are aimed at increasing transparency of the automation by providing system performance information throughout a drive, often with the goal of improving trust calibration [2,9,10,18]. So far, all of the automation uncertainty displays have been presented exclusively visually. This paper discusses the importance and advantages of auditory displays of automation uncertainty, and methods to evaluate such in-vehicle auditory displays.

AUTOMATION AND TRUST

Automation Use

Automation can be defined as, "the execution by a machine agent (usually a computer) of a function that was previously carried out by a human," [17, pg. 231]. In the context of driving, the more functions the vehicle automation performs, the higher the automation level [17]. There are numerous factors that contribute to how drivers interact with automation: automation system reliability, workload, perceived risk, attitude toward automation, and trust in the automation system [16].

Trust in Automation

Developing an appropriate level of trust has been shown to be important for proper automation use [16]. We can define trust as the willingness of a person to be vulnerable to the actions of another, with the expectation the other will perform a specific action [3]. While this definition was initially intended to describe interpersonal trust, it can be extended to the domain of automation and vehicles. Trust in automation should be calibrated so that trust dynamically changes based on the performance of the automation [12]. The system must be transparent about its current status and reliability in order for trust calibration to be possible [11,15]. Current work evaluating automation uncertainty displays has turned from evaluations based on performance outcomes during transitions of control to consider whether the displays allow for trust calibration [13].

DISPLAYS OF AUTOMATION UNCERTAINTY: DISPLAY MODALITY

Visual Displays

Research in this area has primarily focused on the use of visual displays of automation uncertainty [2,10,18]. Displays of automation uncertainty that demonstrate continuous information about the

Table 1. Types of auditory displays.

Display type	Definition	Example
Icon	Naturally occurring [8,9]	Page turning on e-reader
Earcon	Abstract synthetic tone [9]	Melody from a washing machine
Spearcon	Sped up spoken words or phrases [5]	Enhance searching list [7]
Speech	Naturalistic language [5]	"Wait!" at a crosswalk

automation [2,18] and simpler graphical representations [10] have been explored. Despite the type of visual display, the inclusion of automation uncertainty displays in vehicles better prepared drivers for transfer of control [2,10,18], improved trust calibration [10,18], and increased their ability to perform secondary non-driving related tasks (NDRTs) [10]. However, strictly relying on visual displays to convey automation uncertainty can be problematic; driving is a visually demanding task, even with the use of automation. As more responsibility shifts from the driver to the vehicle with higher levels of automation, drivers will likely take up NDRTs, many of which are visual in nature such as checking email, texting, and even gaming [1,4].

Auditory Displays

Presenting automation uncertainty information auditorily would recruit different resources, unused during the driving task, rather than adding another visual element to an already demanding visual task environment [20]. This will allow drivers to more efficiently maintain situation awareness in order to take control if necessary. Therefore, utilizing auditory displays to convey automation uncertainty information could lead to safer transitions to manual control when compared to current, visual displays. In addition to spreading information across attentional resources, auditory displays will also provide needed salience to the automation uncertainty information. This will continue to be an important issue even as level of automation increases as NDRTs are likely to be visual in nature.

There are four primary types of auditory displays that can provide the necessary salient cues and warn the driver of automation uncertainty; see Table 1 for descriptions [5,9]. Previous research has proven that the use of auditory icons as a collision warning system in manual driving reduced response time and led to fewer collisions [9]. Auditory icons have also been tested in other dynamic environments, such as medical settings, as alarm signals. Icons were shown to be easy to learn and to decrease reaction time to alarm signals [6]. The results of these studies show that there is great potential in the use of at least some kinds of auditory displays for presentation of uncertainty information. However, there is still a lack of research, design, and evaluation of auditory displays for automated vehicles and especially for automation uncertainty.

CONCLUSION

Evaluation of Auditory Displays

Research on the use of auditory displays has demonstrated their effectiveness and advantages for performance [5,6,9]. Yet, there is not a standardized method to evaluate auditory displays. Assessment of auditory displays has been done with different techniques such as card sorting, performance enhancement, and usability scales [7,14,19]. General usability scales such as the System Usability Scale (SUS) and Usability Metric for User Experience (UMUX) are typically used for this assessment but lack auditory specificity. The BUZZ scale was developed to elicit feedback from users about auditory specific qualities that can enhance or detract from usability. The scale consists of

11 items and two to three subscales depending on the type of displays used. The BUZZ scale allows for efficient assessment of auditory usability and gives insight into what qualities of the display were particularly useful or not [19]. Additionally, BUZZ can provide feedback prior to fully implementing an auditory display into a system and can serve alongside performance data to determine if preferences and performance align. Using a standardized evaluation tool with auditory specificity will allow for comparison across domains of application for auditory displays. This will allow research to press forward in understanding what type of display is most appropriate for different environments and provide an easy comparison metric.

Future Research Directions

Auditory displays should continue to be explored as an avenue of presenting automation uncertainty to drivers of automated vehicles to ensure that they are attending to the information despite potential visual NDRTs. Research should consider the type of auditory display used to present the information, as well as the frequency of presentation (e.g. continuous or intermittent) that best supports driver awareness of the automation performance. In evaluating auditory displays, we must use rigorous and standardized methods so that results can be directly compared across studies.

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