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DOES SUPPLEMENTARY COMPUTER GENERATED CUEING ENHANCE CONTROLLER EFFICIENCY IN A CONGESTED COMMUNICATION ENVIRONMENT?

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Air traffic controllers are often required to simultaneously communicate with several aircraft over multiple radio frequencies. As a result, during peak loading, it is common for the controller to receive multiple concurrent communications, each from a different aircraft, making it difficult to discern all necessary auditory communications. To address this problem, a modified air traffic control (ATC) interface was prototyped with the goal of increasing controller-to-pilot communication efficiency. This prototype involved an automated text to speech system which displayed supplementary text in an on-screen text box, echoing aircraft transmissions in the event of an indiscernible radio call. The prototype was then evaluated by a group of 35 participants, all with ATC experience at the Air Force controller's school house Keesler AFB, MS. Results of the study indicated text cueing may be useful for improving controller comprehension of pilots' transmissions.

In the future, ATC will be challenged by the expected increase in the amount and complexity of air traffic (Stein & Garland, 1993). The Federal Aviation Administration (FAA) Aerospace Forecast stated that in 2011, total activity at FAA en-route centers increased by 1.8 percent from the previous year to a total of 41.2 million, the fastest growth since 2005. This report also projected the number of aircraft handled at FAA en-route centers, which separate high altitude traffic, to increase by 50 percent (FAA, 2012). As the air traffic load increases, similar increases in communication load expected to occur. Frequency congestion is a sensitive situation that occurs during the communication process between pilots and controllers and "has become a factor that severely constrains the capacity of the National Airspace System (NAS)" (Rantanen et al, 2004).

Controllers often deal with a congested communication environment and are frequently required to communicate with several aircraft over multiple radio frequencies. As a result, during peak loading, it is common for the controller to receive multiple concurrent communications, each from a different aircraft on a different radio frequency, challenging controllers' ability discern audio messages received from multiple pilots simultaneously (this phenomenon is known as "step-on"). As controllers monitor all frequencies through a single earpiece, it is impossible for the controller to interpret concurrent communications, resulting in additional workload as the controller must then decipher the source of each communication and request each aircraft to repeat the communication asynchronously. In some extreme cases, improper or misunderstood communication has contributed to accidents (Rantanen et al, 2004).

This study investigated the communication between pilots and controllers, which is the foundation of air traffic control (Hopkin, 1995). Specifically a method is proposed to improve the existing air traffic controller (ATC) workstation by providing text transcriptions of pilot audio communications to controllers. The text allows the controller to respond without having to transmit a request for a repeat, wait for a re-transmission and then respond. This cumbersome process to overcome "step on" adds exponentially to operator workload and frequency congestion. The proposed system design provides the controllers with accurate transcription of pilot audio communications in a usable and readable format, located in a single window and displayed in a sequential manner. Such a system is expected to decrease the time and steps needed to answer pilots' requests, increasing controller's efficiency and safety within the National Airspace System (NAS).

Background

ATC is a dynamic environment where controllers constantly receive a large volume of information from multiple sources to monitor changes in the environment, make decisions, and perform effective actions in a timely manner (Xing & Manning, 2005). ATC system intricacies include thousands of separate facilities all communicating with each other and handling information via different sources (e.g., radar screens, paper or electronic flight progress strips, radio and interphone communication). Air traffic controllers have to deal with these different sources of information and control complex, dynamic and time-constrained traffic situations to identify and resolve potential conflicts and risky relationships between aircraft. Controllers have to perceive, analyze, comprehend, and anticipate multiple characteristics and flight paths of many aircraft. Incoming and departing aircraft as well as constantly changing aircraft trajectories combine to create new traffic relationships for evaluation. All of this must be performed in real-time and for the purpose of separating aircraft and issuing safety alerts (FAA, 2011).

Audio Comprehension and Task Difficulty

To provide systems and cues that better support the decision making process and enhance situation awareness it is important to understand how humans process information. Wickens' multiple resource theory (MRT) identified the structural dimensions of human information processing and proposes that there are four dimensions (processing stages, perceptual modalities, visual channels, and processing codes) with two categorical levels of each dimension (i.e. separate resources) (2008). This theory suggests that cognitive resources used to process information from one modality compete less with the resources used to process input from another modality than resources used to process input from the same modality. The availability of these resource channels results in a task-sharing benefit if information is distributed across different resources. According to this theory, an improvement in performance would be expected when different input modalities are addressed in a multitask environment (Parasuraman & Metzger, 2006).

Given the potential for decreased understanding arising from simultaneous speakers, targeting information to a second channel, according to the MRT Model, would be useful to explore. Specifically, text cueing may be particularly useful, in the sense that it adds another modality to improve recognition of audio transmissions and provides temporal stability, providing the operator access to each of the communications in the event that simultaneous verbal communications are broadcast over multiple frequencies.

H1: Supplementary text transcription of pilots' communication will increase controllers' comprehension of pilots' transmissions.

Furthermore, text cueing may also improve ATC task difficulty in the sense that it will reduce the need for say-again transmissions as the controllers would possess a secondary, temporally stable means to comprehend pilot's transmissions. As the controllers will not need to follow a cumbersome and time consuming process to request communication retransmission, text cueing should reduce the perceived difficulty of communication tasks.

H2: Text-cueing will reduce perceived difficulty of the communication task.

Memory Recall

Short-term memory accuracy has been a fundamental talent required by controllers to facilitate decisions and actions to ensure safety. According to Tindall-Ford and colleagues, the use of dual-mode presentation techniques (e.g., auditory text and visual diagrams) with students can result in superior learning as compared to equivalent, single-modality formats (Tindall-Ford, et al., 1997). The authors state this modality effect may be attributed to an effective expansion of working memory.

With the use of text transcription on screen, information presentation is shared between auditory and visual methods, in an attempt to control overuse of either mode, which is desired for the design of ATC systems (Cardosi & Murphy, 1995). When controllers listen and read pilots transmissions it is expected the presentation of the redundant verbal information to multiple modalities will improve memory recall. As a result, text cueing should improve controller's recall of what was seen and heard within the air traffic scene.

H3: Supplementary text-cueing will improve memory recall of pilot transmissions.

Distraction

While it is expected that text cueing would have positive impacts to ATC, care must be taken to understand any negative impacts to controller performance and ultimately flight safety. Distraction is a psychological error mechanism that is known to affect performance (Shorrock & Kirwan, 2002). In their paper describing methods for analysis of cognitive errors in ATC, the authors stated that distraction can affect different cognitive domains, such as: perception and vigilance (i.e. errors in visual detection and visual search, and errors in listening); memory (i.e. forgetting or mis-recalling temporary or longer-term information, forgetting previous actions, and forgetting planned actions); and action execution (i.e. actions or speech performed not as- planned). For this reason, potential causes of distraction in ATC should be carefully considered in the design of new aids to ensure that controllers' performance will not be impaired.

Today controllers are not experienced with supplementary text displayed on the side of the radar screen, but focus their visual attention on the radar display and other safety critical visual information. Ensuring safety is a priority for the design of ATCS. Although the text box was carefully designed to reduce distraction such that safety would not be compromised as the controller was forced to move their eyes from the radar display to the text box, it is possible that adding additional features to an already busy ATC workstation could increase controller distraction.

H4: Supplemental text box will increase controller´s distraction.

Methodology

Participants

The sample population involved thirty-five military ATC personnel, including 23 instructors and 12 students at a training installation at Kessler Air Force Base, MS. The students each had a minimum of 2 months of training prior to the experiment. Participation was voluntary and data was collected during a one week period. All of the participants were familiar with the simulated air space and the software used in the experiment.

Experiment Design

The experiment employed as a within subjects design where participants were exposed to two, three minute scenarios: control and experimental. The control scenario consisted of a standard radar screen, familiar to controllers, to use as a baseline to compare performance and did not include any text boxes. The experimental scenario had the text box containing a transcription of audio communication. A brief training scenario was presented to each participant before the scenario to explain how the text should appear on the screen. All of the scenarios used for this study were previously recorded and controllers were not permitted to alter them to standardize scenario experiences and allow comparison of subjects' performance. The scenarios were designed to be as realistic as possible to test the hypotheses of interest. Also, the control and experimental scenarios were developed to be equally complex to provide reliable comparison between controllers' performance regarding just the addition of the technology.

SIGNAL Air Traffic Control Simulation Program software, provided by the FAA, was used to develop and record the scenarios. The Multi-Modal Communication (MMC) System (Finomore et al, 2011) software was used to provide speech-to-text transcription. For the purpose of this study, a 100% accurate transcription of the audio communication was assumed since the objective of the study was to collect initial data of controllers' performance and perceptions of the advantages of the additional text, and not to test the technology itself. Text display was delayed by a period of time consistent with the recognition time required by the MMC system.

Measurements

Participants were required to monitor the display as they would in a regular air traffic control task; however they could only interact with the fictitious scenario pilots by clicking the mouse one time if they felt that a "SAY AGAIN" transmission was necessary. The number of mouse clicks was applied to test the first hypothesis. After the controllers were exposed to the air traffic scenario, a post-study questionnaire was administered regarding what they saw and heard during the experiment. To test the second and fourth hypotheses, participants' self-reported feelings of perceived difficulty and distraction were applied. For the third hypothesis, a query technique (Adams et al, 1995) was used to measure recall of specific pilot transmission requests. The post-test questionnaire also asked the participants to assess the realism of the scenarios and to indicate whether they found text cueing useful.

Results and Discussion

The two scenarios were perceived to be equally realistic. Also, 33 of the 35 participants reported they found the text cues useful in the performance of their task.

The primary dependent variables for this study were number of clicks (H1), self-reported difficulty (H2), percent correct of recall answers (H3), and self-reported distraction (H4). The main independent variable was scenario. Demographic and other background data was collected through a pre-study questionnaire and were considered as potential covariates during the analysis in order to explore their potential influence on controllers' performance. A t-test was run on the data with a 95% confidence interval to determine statistical differences between experimental and control scenarios for each hypothesis. In the cases that the t-test showed significance, a stepwise regression was conducted to determine if other independent variables may have also influenced the dependent variable.

For H1, t-test indicated that number of clicks for the experimental group, mean with a standard error of 2.34, were significantly lower than for the control group, mean(2.34 with a standard error of 1.327(t(68) = 2.638, p < .010). Therefore, stepwise regression was run and the model indicated an adjusted R^2 of .477 and included the additional independent variables of open mind, familiarity, multitask and experience ($F(69) = 13.609$, $p < .01$). Participants clicked the mouse less frequently when they reported they believe that new technologies can improve ATC, ; are familiar with the text on-screen technology; are able to multitask and feel comfortable listening and reading at the same time and had less experience in ATC. Individuals with more experience clicked more frequently and may have been more resistant to the change in presentation as it was it significantly different from their standard workstation.

The findings for H1 indicate that the experimental group had an increase in comprehension, requiring fewer interactions for communication clarification. The reduced number of transmissions would also potentially reduce frequency congestion. Another important contribution of the reduced number of transmissions is that it inherently reduces time needed to answer each pilot´s transmission, allowing controllers to continually focus their attention on monitoring the airspace instead of trying to comprehend the previous transmissions.

For H2, t-test results indicated that perceived task difficulty for the experimental group, mean rating 8.17 with a standard error of 2.065, was not significantly different than the control group, mean rating of 7.40 with a standard error of 1.802 ($t(68) = -1.665$, $p = .100$). The findings for H2 indicate that there is no significant difference in perceived difficulty of the task due to the use of the new technology. However, it should be recognized that the controllers were not required to conduct each dialog to its completion, only indicate through the mouse click when additional information was required.

For H3, t-test results indicated that recall in the experimental group, mean of 3.14 with a standard error of 1.52, was not significantly different than the control group, mean 3.20 with a standard error of 1.21($t(68) = 0.174$, $p = .862$). The findings for H3 indicate that there is no significant difference in memory recall due to the use of the new technology. The role of memory has been heavily researched in the air traffic environment and its importance concerning whether the controllers should retain memory or not has been debated. Some studies suggest that controllers deal with a constantly dynamic environment and therefore dynamic memory changes frequently. Hopkin (1980) stated that the ability to forget the information is as important as the ability to remember, allowing controllers to deal with just the necessary information required and avoid the workload associated with keeping memory. Even if doesn't improve memory recall, the text on screen might still be a good aid because controller can use the text to refresh his/her working memory.

For H4, t-test results indicated that distraction for the experimental group, mean 6.09 with a standard error of 3.381, was significantly higher than the control group, mean 4.57 with a standard error of 2.779 ($t(68) = -2.047$, $p < .05$). Therefore, a stepwise regression was run and the model indicated an adjusted R^2 of .093. This model included the scenario and additionally indicated that participants who self reported high ability to multitask and feeling comfortable with reading and listening at the same time experienced lower distraction. Due to the very low variance explained, definitive conclusions cannot be drawn for Hypothesis 4 at $F(69) = 4.537$, $p = .014$. Although distraction did appear to increase with the on-screen technology, no definitive conclusions could be drawn due to the very low variance explained in the model. This is an important finding since the low adjusted R^2 may indicate that while there was significantly more distraction in the experimental condition, the distraction may not have been due to the additional text. Other factors yet unknown may have also played a role.

Conclusions and Recommendations

There has been significant advancement in speech-to-text technology in recent years. The application of this technology is constantly increasing, specifically in military systems (Weinstein, 1991). The resulting systems provide the immediacy available from voice communications while providing persistence of information to aid deconfliction of simultaneously-broadcast communications and to serves to aid short-term memory.

This research represents the first step towards understanding the impact of speech-to-text technology for aiding the communication between air traffic controllers and the multitude of aircraft they control. In this study, we assumed that text transcription of pilots´ transmissions were completely accurate and measured the controller's need for repeat auditory communication, their recall of relevant information and their perceptions of the system, the difficulty of using the system. The results indicated that the controller's valued the system, would make fewer requests to the pilots for "say again" communications, and had similar recall. The controllers did not perceive a difference in difficulty with the reduction of text cueing, but were not required to complete their full cycle of communication tasks, associated with a "say again" communications. Therefore, it is possible that the controllers did not consider the time savings and reduction of tasks associated with the reduction in these tasks when rating difficulty. These results are encouraging and support the application of this technology to provide automated transcriptions of pilots' communication to enhance controllers' efficiency.

Despite the encouraging results, the participants' rated perceived distraction higher for the system involving text transcription than for their traditional system. This result provides a cautionary warning as it signals the possibility that the provision of the text transcription window could distract the air traffic controllers attention away from higher priority displays, such as the radar scope. As a result, additional research is recommended to understand the safe application of the proposed technology to enhance controllers´ efficiency. Although every effort was expended to recreate a realistic ATC workstation and environment, a more accurate interactive environment or training workstation could provide additional insight into this application. The use of an eye tracking to determine time spent reading the text, and therefore the time spent with eyes away from the radar scope is also recommended as it could provide insight into the impact that text cueing of pilot communications has on system safety.

Additionally, further research should investigate the effect of the reliability of text transcriptions on controller´s efficiency. Further, training procedures should be developed and included in future studies as the participants identified the lack of training with the technology as a barrier to the full utilization of the system.

This paper proposes an engineering tool designed to improve the cognitive process of the air traffic controller to support timely human decision making. An attempt was made to provide an overview of the cognitive factors that must be considered to provide a basis for the development of this tool to enhance efficiency and critical decision making. It is believed that by optimizing and providing all the information needed by the controller in a timely manner, the ATC system may benefit and that with highly optimized and correctly designed solutions, providing the potential to enhance the time-critical aspect of controllers decision making in an increasingly congested communication environment and potentially permit the controller to successfully control additional aircraft. In this specific application, controllers will be able to read what was said instead of just relying on auditory memory and comprehension. This advance could lead to increased efficiencies in the NAS throughout reduced frequency congestion and potentially error reduction associated with misunderstood transmissions.

This research was an exploratory study to determine the effectiveness and efficiency gaining potential of this new technology and whether further research is warranted. A number of contributions and implications of the use of the text technology were described. Applications in training and real-time air traffic are seen to be promising for the proposed technology. Additionally, future research is recommended to guarantee the advancement of the technology and its application to enhance the ATCS efficiency and safety.

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