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Controllers identify vertical separation in aircraft depicted on 2-D radar displays by calculating altitude from numerical values. This is used to create a 3-D mental image to determine vertical spacing; a mentally fatiguing practice. Current stereoscopic display technology exists that may allow reduction of this aspect of controller workload. With a near doubling of traffic expected within the next two decades (FAA, 2012), controllers' abilities to rapidly interpret spacing and maintain awareness will become increasingly imperative to safety. A stereoscopic radar simulator was developed and field-tested with 35 USAF controllers. It presented a top-down view, similar to traditional radar displays, however, altitude was depicted through stereoscopic disparity, permitting vertical separation to be viewed, rather than calculated.

Air traffic growth is expected to increase 90% over the next two decades (FAA, 2012). This increase in traffic volume and the limited capacity of the current national airspace system (NAS) has driven the Federal Aviation Administration (FAA) to plan a comprehensive overhaul of Air Traffic Control (ATC) operations (Marsa, 2009). The FAA's Next Generation Air traffic Control or "NextGen" initiative is an effort designed to increase the NAS capabilities; especially with regards to safety and aircraft efficiency. New technology incorporated under NextGen will permit aircraft to continuously broadcast aircraft location, speed, and flight information and provide this information in each aircraft to create automatically self-separating traffic (Mc Callie, 2011). Therefore controllers are expected to transition to passive roles of monitoring self-separating traffic and become responsible for monitoring larger numbers of aircraft. As a result, the workload, tasks and workstations of these controllers will change dramatically (Prevot et al, 2008).

The impact of NextGen driven changes upon controller responsibilities and duty requirements must be clearly understood to ensure minimal impact to flight safety. Currently, air traffic controllers must rapidly interpret vast amounts of data and dynamic traffic information to actively direct air traffic away from detected conflicts. Under NextGen, despite automatic self-separating aircraft, controllers will still be required to monitor the same data, but will only issue directions if the system fails to initiate separation actions. Unfortunately, research has shown that human vigilance wanes rapidly when active engagement, in this case issuance of instructions, is omitted (Parasuraman et al, 1993).

It is therefore, imperative to develop improved methods for delivering information to air traffic controllers that mitigates the negative impacts of passive monitoring. Final responsibility for flight safety will always remain with human controllers; thus their ability to observe the increased traffic volume accurately and in an intuitive manner will be increasingly critical for maximizing efficiency and safety. Toward this end, a simulated stereoscopic radar workstation was developed and field-tested with 35 USAF controllers. This workstation presents a view similar to traditional radar displays but depicts altitude through the use of stereoscopic disparity, permitting vertical separation to be visually represented as plainly as lateral separation.

The goal of this study was to determine the potential impacts of this stereoscopic workstation. Of particular interest were impacts to fatigue reduction, decision-making, perceived workload and situation awareness. From a human factors (HF) perspective, the displays must not only be intuitive, they must also accurately present the information and raw data the controller needs to support rapid decision making. For air traffic controllers this equates to depicting aircraft to permit easy understanding and projection of lateral and vertical separation. Therefore the research question is: *Does stereoscopic presentation of digital radar displays enhance controller performance and effectiveness?*

Background

ATC is a dynamic environment where controllers constantly receive a large volume of information from multiple sources to monitor changes, make decisions, and perform effective actions (Xing & Manning, 2005). ATC systems must be designed to provide the operator with the information and capabilities necessary to support the controllers (Endsley & Garland, 2000). The controller must formulate an accurate representation of the situation, given many sources of information about aircraft, sectors, and flight rules and then direct aircraft to maintain a safe airspace. These activities are best described as the mental modeling that a controller must perform to comprehend the aircraft positions in spatial orientation to one another.

Stereoscopic Displays

Research has demonstrated that stereoscopic display technologies are considered, "indispensible" for viewing complex and extensive high-dimensional scientific data and objects especially in a dynamic and temporal (4-D) capacity (Chau et al, 2012). However the applicability of stereoscopic viewing for the purpose of air traffic control potential has been met with mixed results (Parker & Wallis, 1948; McIntire et al, 2012). In an ATC context side-view combined with a top-view, commonly referred to as "coplanar", slant view and pilot perspective stereoscopic methods have been evaluated. An inherent limitation to slant view or pilot perspective stereoscopic methods is that lateral separation loses scale as aircraft are depicted farther away just as in real life the targets become smaller and more difficult to discern at a distance. This limitation renders these views useless for the purpose of determining whether a minimum separation exists between aircraft. According to Tavanti et al, there is a consistent deficiency in this type of display with regards to the unknown distance along the depth axis affording little to no reference to the horizon line (2003).

Virtual reality (VR) caves and other types of semi-immersive control interfaces have also been investigated for air traffic control operations and have been shown to have limited applicability (Persiani & Liverani, 2000). These display methods, aside from being physically cumbersome and requiring complete body reposition for 360 degree observance, the displays are view limiting and often disorienting due to a lack of ground and focal reference. Furthermore, these immersive displays lack the ability to provide a large scale depiction containing an operator's entire area of responsibility within a single field of view (FOV).

If stereoscopic viewing is to be useful for air traffic control operations, it must simultaneously depict lateral and vertical separation. Recent advances in technology allow for improved "top-down" viewing of a 3D world. As a result, this study focuses on the effects of providing a top-down stereoscopic view for air traffic control operations. Such a system maintains the perspective available to controller's in today's system to allow the controller to rapidly grasp the lateral separation, while using stereoscopic disparity to depict altitude, permitting the controller to assess the vertical separation based on perception of depth afforded by the stereoscopic top-down view. The following sections highlight the expected effects of incorporating stereoscopic into traditional ATC displays through a top-down view

Situation Awareness

Endsley indicated that operators and decision makers are often bombarded with far too much data to sort, leaving them less informed as they are unable to quickly access the information they need in a timely manner (1995). Situation awareness (SA) is the focus of an air traffic controllers training and the development of this skill, as well as the ability to maintain it, is critical to airspace safety. SA is defined by Endsley as, "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (2000). Creating a stereoscopic view of a traditional top-down digital radar displays affords the controller the best possible perspective, preserving both the scale and lateral separation while providing a scale-accurate depth perspective to assess vertical separation. By providing simultaneous vertical and lateral separation, it is hypothesized that situational awareness will be enhanced.

H1: The use of stereoscopic digital radar displays will have a positive effect on controller situation awareness and conflict detection.

Mental Modeling, Memory and Recall

Hopkin stated that a controller's ability to forget the last altitude or vector given to an aircraft permits them to replace previous data with the current or next assigned characteristics (Hopkin, 1980). This memory management may allow a controller to maintain better awareness of their assigned traffic (Gronlund et al, 1997). Rantanen and colleagues described a controller's cognitive task as a producing a temporal mental picture because temporal demands require controllers to "anticipate aircraft trajectories and pilot intentions well into the future, plan their actions, and then execute the planned actions at a proper time and in an appropriate sequence" (Ratenan et al. 2004).

This is commonly referred to as “The Picture” by air traffic controllers. Specifically, Shorrock states that there is an absence of emphasis on developing mental imagery and adapting it into technology design (2007). In traditional ATC, controllers build mental models, specifically altitude depiction, by complex mathematical calculations based upon text cues. Stereoscopic displays as investigated here eliminate the need for such calculation and will present the 3D mental model intuitively. Given the importance of the mental model to air traffic controller performance and the effect of recall accuracy on establishing a reliable mental model, hypothesis 2 is as follows:

H2: The use of stereoscopic digital radar displays will have a positive effect on controller recall accuracy of aircraft vertical position.

Perceptions of Workload and Task Difficulty

It has been extensively studied and agreed upon by many in the human performance field, that temporal and mental demands comprise the largest portion of a controller’s workload in ATC (Rantanen et al, 2004). The limiting factor to the growth of the air traffic volume is also known to be the air traffic controllers’ limitations in controlling aircraft in a given sector. It has been determined as recently as 2004 that the maximum safe operating number of active aircraft per operator is 15 at a time (Erzberger, 2004). Workload for controllers is often driven by the amount of mental calculations they must perform. An appropriate stereoscopic display reduced the necessary number of mathematical calculations, thus reducing overall controller workload. If workload is reduced, the optimal number of aircraft per controller may be increased. In order validate this belief, it is hypothesized that:

H3: The use of stereoscopic digital radar displays will decrease controller perceived workload.

H4: The use of stereoscopic digital radar displays will decrease controller perception of task difficulty.

Methodology

Participants

For this study the sample population was provided by the ATC technical training school at Keesler Air Force Base, MS. The study involved 35 USAF ATC instructors and students. Participation was voluntary and the study lasted one week. A primary advantage of this population was that all participants were familiar with standard air traffic procedures and displays. Experience levels varied from 2 months, to 30 years. The average years of ATC experience was 7.29 years. The average age of participants was 29.1 years and 26 of the 35 participants were male.

Experiment

The experiment employed a within subjects design with two conditions: control (standard display) and experiment (top down stereoscopic display). The experiment was balanced with half the participants assigned to either the control or experimental condition first to limit any learning or order bias. All scenarios involved a pre-recorded ATC scenario to limit the participants’ interaction (i.e. participants could not alter aircraft trajectory on screen). Each scenario lasted approximately eight minutes. Participants were provided with a brief training period prior to the start of the study. The experiment was designed to evaluate the controller recognition of vertical separation conflicts when viewing a traditional 2D top-down ATC display versus a top-down stereoscopic ATC display. A pilot study was conducted with six additional volunteers to ensure validity and provide feedback to permit the display design to be refined.

Equipment

Commercial-off-the-shelf equipment was used with the exception of the SIGNAL FAA simulation software, which is was provided by the FAA. The remainder of the suite included an ASUS VG236 23.5",120Hz stereoscopic LCD display monitor, and NVIDIA 3D Vision software, USB Controller, IR Emitter and associated active shutter stereoscopic glasses operated from a Dell Precision M4600 mobile workstation.

The experimental scenario was provided stereoscopic images with active shutter 3-D glasses on the ASUS 23.5” monitor. This displayed provided a top-down display with a ground reference plane depicted by range rings having near zero disparity and the aircraft having disparity that is proportion to altitude such that the aircraft “protruded” from the display above the ground plane. The aircraft were provided with accompanying data blocks, which were assigned the same disparity as the aircraft. Through this depiction, the lateral and vertical separation of the aircraft were equally evident without the need to read and calculate numerical values to determine altitude separation.

***Figure 1.* The experiment equipment in use.**

Data Collection

Data was collected with pre- and post-treatment questionnaires. The pre-test questionnaire collected participant demographics as well as relevant and potentially influential variables. In addition to questionnaires, single mouse clicks, used by participants to indicate when they detected potential conflicts, were the only real-time measurements. After each scenario a questionnaire was administered to evaluate effectiveness of the technology through collection of specific performance measures. This questionnaire included a primary recall accuracy instrument, which was a screen capture from two minutes prior to the scenario end with the three-digit altitude codes blanked out, to be filled in from memory and questions regarding the relative locations of aircraft within the environment. The questionnaire also contained questions about the participants' perceptions of the technology and, confidence in their answers and a place for open ended feedback. There were no time limitations placed on any questionnaires.

Results

SPSS was used for all statistical analysis. The independent variable was display condition and dependent variables are indicated in each hypothesis. For all hypotheses, a *t*-test was first conducted with a 95% confidence interval (CI) to test for significant difference between control and experimental group means. If significance was found, a stepwise regression was performed to determine the influence of participant demographic and personality measures on the dependent variable. Distribution normality was assumed as the t-test is considered robust with respect to the assumption of normality, and homogeneity of variance was evaluated as assessed by Levene's Test for Equality of Variances.

To investigate the hypothesis that "The use of stereoscopic digital radar displays will have a positive effect on controller situation awareness and conflict detection" it was predicted that the stereoscopic display would increase the accuracy of the detection of on-screen conflicts. As the paths of the aircraft within the scenarios were depicted to provide a pair of lateral position conflicts, but never to provide conflict in both lateral position and altitude, the operators should not have had to indicate a conflict. Therefore, a higher number of clicks indicated a lower awareness of actual conflicts. The t-test indicated, the number of clicks was larger for the control group, 3.40 clicks with a standard deviation of 1.33, than the experimental group, mean of .91 clicks with a standard deviation of 1.27 ($t(68) = 7.991$, $p < .01$). This finding indicates a significant difference in SA and conflict detection performance between the display conditions. The stepwise regression model resulted in adjusted R^2 of .613 with Fatigue, Multitask, and Years of Experience in ATC included in the model at ($F(69) = 28.357$, $p < .01$).

To test the hypothesis that "The use of stereoscopic 3-D digital radar displays will have a positive effect on controller recall accuracy of aircraft position", we investigated the effect of display condition on recall accuracy. Surprisingly, the t-test indicated the control group answered a higher number of questions accurately, recalling and average of 4.81 questions with a standard error of 1.11, as compared to the stereoscopic condition, which averaged 2.73 correct questions with a standard error of 1.15 ($t(68) = 7.679$, $p < .01$). The stepwise regression resulted in an adjusted R^2 of .562 with depth perception deficiency and SA/distraction included as significant factors in the model at ($F(69) = 30.489$, $p < .01$).

Several participants reported having trouble recalling the exact location of the highest or lowest aircraft in the scenarios after viewing the stereoscopic display condition. They attributed the obvious safe vertical aircraft separation to their inability to recall. Participants in the stereoscopic display condition reported immediately recognizing aircraft that were operating in safe vertical proximity and dedicated fewer attentional resources to tracking and monitoring those targets, thus reducing memory recall of those tracks. Since it has been claimed that forgetting information may be just as important as remembering it in a dynamic memory situation like ATC (Hopkin, 1980), as the status of each aircraft track changes so rapidly, recalling the last or last several altitudes, (or other flight characteristics), may interfere with the controller's ability to remember the current or most recent altitude. It is therefore possible that the stereoscopic display condition allows the controllers to rapidly determine priorities, or "filter through the chaff", based upon which aircraft are more likely to require separation instructions from those which are clearly operating with safe separation. However, this finding requires further investigation.

To test the hypothesis that the use of the stereoscopic digital radar display would reduce perceived workload we investigated participants' post-conditions assessment of perceived workload. The control group reported a higher perceived workload, average rating of 4.74 with a standard error of 1.15, than the experimental group, 2.03 with a standard error of 1.89 ($t(68) = 8.61$, $p < .01$). The stepwise-regression included self-reported distraction along with display condition as significant and showed an adjusted R^2 of .598, which was significant ($F(69) = 52.236$, $p < .01$). Controllers reported that the experimental treatment "seemed" easier and they were able to comprehend vertical separation more readily, making the tasks seem simpler.

To test the hypothesis that the stereoscopic digital radar display will reduce the perception of task difficulty, the rating of task difficulty was evaluated. It was found that the control group reported a higher level of task difficulty, reporting a mean value of 5.31, with a standard error of 1.79, than the experimental group, with a mean value of 3.61 and a standard error of 1.00 ($t(53.271) = 4.894$, $p < .01$). A stepwise-regression resulted in a model which included self reported distraction, Aviation Experience, and Computer Use to produce an adjusted R^2 of 360 ($F(69) = 10.695$, $p < .01$).

It is noteworthy that not only were the majority of the hypotheses confirmed during this experiment, but the participants valued the innovation. When asked if they found the stereoscopic display useful in the performance of their task, 88.6% of the air traffic controllers answered affirmably.

Conclusions

This was an exploratory study showing strong potential of top-down view, stereoscopic displays to increase controller performance when performing vertical and lateral separation comprehension and conflict detection. The reduced perceived workload and task difficulty indicate that the use of such a display may have the potential to permit controllers to monitor more aircraft with potentially less loss of awareness. Furthermore the study also implies that controllers, with the help of a more intuitive and less mentally tasking display, may be better prepared to maintain vigilance over larger sectors for longer periods of time. Finally from a safety standpoint the increased awareness and detection of potential conflicts also indicate that controllers may be better equipped to maintain safe separation of aircraft thereby permitting an increase in traffic safety in the system as a whole. However, these implications require further study with more realistic scenarios.

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