



The impact of alerting design on air traffic controllers' response to conflict detection and resolution



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ABSTRACT

Purpose: s: The research aim is to develop a better design of auditory alerts that can improve air traffic controllers' situation awareness.

Method: Participants are seventy-seven qualified Air Traffic Controllers. The experiment was conducted in the Air Traffic Control operational rooms of the Irish Aviation Authority at Shannon and Dublin. Participants were advised that the trials were in relation to the Operational Air Traffic Control system. ANOVA with two between-subject factors (alerting designs and experience levels) were conducted to analyze the ATCO's response time for three critical events. Bonferroni test was performed for post-hoc analysis on mean differences of response time.

Results: There is a significant difference in ATCO's response time between acoustic alert and semantic alert across STCA, APW and MSAW. No significant main effect of controllers' experience on ATCO's response time for STCA and APW. Also, there is no significant interaction between alerting design and experience level on ATCO's response time across STCA, APW and MSAW.

Conclusion: The results demonstrated that the acoustic alert deployed within the ATM system provides level-1 Situational Awareness to ATCO's compared with an semantic alert which provides not only level-1 of situational awareness for perceived alerts, but also level-2 and level-3 of situational awareness to assist ATCO understanding of critical events and therefore develop more suitable solutions. Consequently, human-centered design of a semantic alert can significantly speed up ATCO's response to STCA, and APW. Furthermore, the semantic alert could alleviate expertise differences by promoting quicker response times for both novice and experienced air traffic controllers.

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1. Introduction

The Air Traffic Management (ATM) System provides three kinds of alerts which are designed to alert controllers to three distinct critical risks, Short Term Conflict Alert (STCA), Minimum Safe Altitude Warning (MSAW), and Area Proximity Warning (APW). Activation of any of these three alerts by acoustic design indicates a potential conflict of aircraft, conflict between aircraft and prohibited airspace and conflict between aircraft and terrain, therefore the air traffic controller is expected to respond and resolve the potential conflict as fast as possible to ensure the safety of the

aircraft. The Operational Air Traffic Control system is deployed in five countries within Europe, Ireland, Denmark, Sweden, Austria and Croatia, and the air traffic controllers (ATCO) within these five countries all operate a harmonized system which provides three critical alerts using the same audio alerting schema. Furthermore, the system is seen as a major step in achieving the European Union aspiration of harmonized ATM systems across Europe in support of Single European Sky (Eurocontrol, 2015).

The activation of the STCA alert on the system provides a 90 s warning, that unless appropriate action is taken by air traffic controllers to resolve the conflict, significant risk of collision between aircrafts exists. This introduces time pressure on the ATCO's to identify the nature of the alerts and respond with air traffic control instructions which resolve the conflict situation (Eurocontrol, 2014). However, previous safety recommendations from aircraft accidents linked to controlled flight into terrain and aircraft

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collision revealed that most of these accidents occurred in circumstances where MSAW and STCA were available to ATCO's. All of these accidents demonstrated that alerting system configurations provided alerts of the impending situation, but ATCO's failed to provide timely safety advice to flight crew (NTSB, 2006). The report also indicated that ATM systems were not adequately designed so as to provide ATCO's with effective situation awareness (SA) to make timely decisions. Air traffic controllers must make a rapid judgment of the situation that is being signaled by the automatic alerts provided by an ATM system, and then take the appropriate decision to ensure aviation safety. Interestingly research spanning from 1977 to 2008 has demonstrated that decision errors in aviation may be contributing to up to 60% of all aviation accidents (Jensen and Bernel, 1977; Buch and Diehl, 1984; Diehl, 1991; Li and Harris, 2008). Furthermore, recent accident investigations found that poor air traffic control might impact on aviation safety (Daramola, 2014). The current ATM system is reactive and inefficiencies result in delays with associated negative impacts on economy and safety. Therefore, there is an urgent need to develop novel and strategic methods for ATM, making use of current and future technologies to enable better planning and thereby increase capacity and efficiency, without jeopardizing safety (Schuster and Ochieng, 2014).

1.1. Alerting designs and ATCO's' situation awareness

The current Operational Air Traffic Control system has a potential design issue which is an alert activation for STCA, MSAW or APW might be misinterpreted as the acoustic signal for all three alerts is the same (Beep-Beep-Beep-Beep). This has the potential to induce an ATCO's into misjudging the type of critical alert being presented and in the worst circumstances the ATCO's response may be to simply silence the acoustic alert, not solve the separation risk for example, thereby weakening system safety. Design of salient alerts for ATM systems might be excellent at capturing ATCO's attention and increasing SA. However, this salient alert might immediately divert operator's attentional resources away from the ongoing task, incurring other issues such as startle and primary task error by distraction (Imbert et al., 2014). Suitably human-centered designs of automated alerts in ATC can have significant effects on controllers' performance and reduced cognitive workload (Laois and Giannacourou, 1995; Tobaruella et al., 2014), with increased capability to perform complex task management (Wickens and Holland, 2000). However, inappropriate design of automation can present many disadvantages and create potential risk leading to accident/incidents, including loss of SA, and substituting the human operators outside system control loop (Durso et al., 1998; Endsley, 1995). Intensity of audio alert designs can be modified based on task demands and working environment in order to optimize ATCO's performance. In addition to audio intensity level, the semantic content of an auditory alert that conveys the appropriate hazard level is the central component to increasing operators' SA (Edworthy and Hellier, 2006). Appropriate design of automation in ATM systems can assist in moderating ATCO workload and improving SA by facilitating a better match between task demand and cognitive resource (Kaber et al., 2006). The effective coordination of the human-automation team is crucial to the successful implementation of ATM systems in the future. Designing and managing human-automation teams require an understanding of principles of cognitive system engineering, allocation of function and team adaptation. It is a holistic approach by distributed cognition coordination to rapidly changing situations (Langan-Fox et al., 2009). Future human-centered design of ATM system shall be based on a strategic, collaborative and automated concept of operations, as high performance in conflict detection and

resolution has the potential to increase both airspace efficiency and the safety of aviation (Schuster and Ochieng, 2014). Based on the above literature review, current research will investigate ATCO's SA between the current acoustic alert and new semantic alert developed by the authors. Therefore, the first null hypothesis of current research is " H_0 : designs of alert has no significant effect on ATCO's SA"; and the alternative hypothesis is " H_1 : design of semantic alert can improve ATCO's SA compared with acoustic alert".

1.2. Working experience and information processing

Task performance between novices and experts are different, experts are better at predicting future states than novices (Roth and Woods, 1988; Wickens, 1992). Experts' mental representations are more organized and conceptually richer than novices; as a consequence, expert's decision-making relies on a deep understanding of situations, whereas novices are based on rigid rules (Hoffman et al., 2007). In circumstances of time-limited situations, such as ATC, the faster the mental processing of the task the better the performance and the faster the processing is completed, the more time is available for subsequent tasks (Salthouse, 1992). Experienced controllers showed a higher proportion of relative gaze duration and relative fixation duration on relevant areas within the orientation phase than in the other phases. The reason could be that experts spend more time than novices in forming a conceptual understanding of the problem in order to build up a richer and more organized mental representation of the situation (Bruder et al., 2014). Research in aviation demonstrated that experienced pilots performed in a superior manner compared with less experienced pilots in a study at recognizing deteriorating weather conditions (Wiegmann et al., 2002). Furthermore, experts and novices differ in response to dynamic situations; experts were considerably more context-dependent in evaluating situations than novices, allowing them to evaluate situations more holistically than novices (Strauch, 2004). The increased experience in the environment should lead to the formation of higher level structure such as schemata or mental models, which can be used to organize the complexity and multiplicity of objects in the environment; it can be observed by experienced controllers generating a cognitive picture more easily and faster than novice controllers (Endsley and Bolstad, 1994). There is a need to investigate air traffic controller response time between novices and experts, therefore, the second null hypothesis of current research is " H_0 : working experience has no significant effect on ATCO's response time"; and the alternative hypothesis is " H_1 : experienced ATCO's response time quicker than novice's response time".

1.3. Design of alerts and ATCO's experience for conflict resolution

Monitoring aircraft information is an important part of the ATCO's task. Previous research identified a number of safety concerns with ATM systems, such as lack of uniqueness of alarms, multiple false alarms, alarms being counter intuitive and alarms being annoying and increasing ATCO's workload (Ahlstrom, 2003; Newman and Allendoerfer, 2000). In the ATC domain, the activation of a safety alert means that the air traffic controllers must resolve a critical situation, often while under time pressure. Auditory alerts can attract the operator's attention regardless of where visual attention is directed, if presented at an audio level to sufficiently overcome background noise. However, the effect of auditory alerts can be diminished if the presentation of an acoustic alert is too high which can lead to controllers being startled. Verbal warnings tailored to specific hazard situations may improve hazard-matching capabilities without substantial trade-off in perceived annoyance (Baldwin, 2011). The main purpose of ATC is

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