DESIGNING AN INTERRUPTION MANAGEMENT EXPERIMENT: EVALUATING THE WORKING AWARENESS INTERRUPTION TOOL (WAIT) FOR AIR TRAFFIC CONTROLLERS

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Abstract

Designing an experiment to evaluate a complex phenomenon such as interruptions requires the careful consideration of competing trade-offs between realism and controllability. This paper presents the design of an experiment used to evaluate an interruption management tool, the Working Awareness Interruption Tool (WAIT) interface. An overview of the features being tested and the experimental protocol is described. The paper also discusses how the competing demands of realism and the need for repeatability and experimental control influenced experiment design decisions. Lessons learned and recommendations for other researchers studying interruption behavior and tools are presented.

Introduction

Collaboration between multiple operators is a critical element of many complex socio-technical systems such as medicine, transportation, and process control. Operators of these systems must regularly and frequently deal with interruptions from collaborators. These interruptions can provide valuable information relevant to the task at hand; however, they can also divert attention and demand resources at inopportune moments. For example, interruptions by air traffic controllers while flight crews were in the middle of pre-flight checklists were contributing causes to both the crash of Northwest /Airlines flight 255 in Detroit in 1987 (NTSB, 1988) and the loss of Spanair flight 5022 in Madrid in 2008 (CIAIAC, 2008).

Many systems and interfaces allow operators to manage interruptions by permitting, delaying, or rejecting them. This can be as simple as a mute button on a telephone, or setting a status on a chat application. However, often the operator must manage interruptions without knowledge of the urgency of any incoming interruptions. At the same time, it can be challenging for an operator who needs to interrupt a colleague to know when to time their interruption. Field visits to Air Traffic Control (ATC) facilities in North America and questionnaires and interviews with controllers showed this is a common challenge in ATC. There is limited support for interruption awareness and interruption management as controllers are often physically separated and only have voice communication methods to interact with each other.

To address this issue, we are developing the Working Awareness Interruption Tool (WAIT), which is designed to reduce the negative impacts of interruptions in the ATC context. The WAIT tool provides a set of features designed to prototype methods of indicating the availability of a controller to be interrupted and of indicating the urgency of an interruption. The WAIT tool is also designed to be integrated with existing controller-controller communication interfaces to preserve the ATC context. In order to more fully evaluate the potential of the WAIT tool, an interactive part-task experiment was developed. This experiment provides a way of systematically examining how well the WAIT features work in an interactive, complex environment, for supporting improved interruption awareness and management. This paper discusses the WAIT tool features examined in the experiment and some key challenges in designing an experiment to evaluate interruption decision support tools.

Background

The "interruption" concept has been studied in many fields such as psychology (Ledoux, 2003; Shum et al., 2013), engineering (Lu, 2005), and computer science (Hodgetts & Jones, 2007; Khalil, 2006), and it is associated with other concepts such as "multitasking" (Law, 2004). Many researchers worked on creating a formal definition of interruption. For instance, McFarlane (1997) gave a general definition to it as "the process of coordinating abrupt changes in people's activities" (p. 67).

Interruptions are common in time-critical, dynamic and collaborative environments, such as ATC. While the information provided can be valuable and task-relevant, interruptions also create distractions and consume attention resources (McFarlene & Latorella, 2002). Interruptions are known to have impacts on task performance (e.g. Rogers & Monsell, 1995). There has been significant previous work on technologies for controlling when interruptions occur (e.g. Wiberg & Whittaker, 2005) and improving recovery from interruptions through techniques such as video replay (Grundgeiger et al., 2010; Sasangohar, 2009). However, there has been relatively little work done in applying these techniques to the fast-paced, collaborative, distributed safety critical operations that occur in air traffic control, in part because of the challenges of integrating with other task demands in such a complex operational environment. The following subsections discuss this previous work in more detail.

Effects of Interruption

Interruptions can generate positive effects; Van Bergen's (1968) review of decades of interruption research in psychology found that people could more easily recall items from interrupted tasks than from uninterrupted tasks. However, more recent research has found that interruptions affect task performance negatively and can produce errors that cannot be overcome afterwards. For example, McFarlene and Latorella (2002) showed that interruptions can induce stress, increase the time it takes for people to resume working on an interrupted task, and increase task errors.

Controlling the Occurrence of Interruptions

To mitigate the negative effects of interruptions techniques have been developed to assist people in resuming work on the interrupted task, such as providing a list of historical events (St. John et al., 2005) and video or instant replay (St. John et al., 2005, Sasangohar, 2009, Scott et al., 2006). These techniques focus on facilitating task resumption after an interruption has occurred. Interruption management, however, also concerns facilitating the pre-interruption phase, to determine, for example, whether an interruption should be initiated or should be responded to at the given time.

The rapid growth of various communication tools (e.g. answering machines, voicemail) and social communication applications (e.g. MSN Messenger) also fosters new and innovative ways to support interruption management. These social tools usually provide their users with an awareness indicator that allows them to set their status either from built-in statuses such as “Away”, “Busy”, and “Available” or by creating custom ones, while answering machines and voicemail give people the opportunity to postpone an interruption until a more appropriate time. Such techniques provide people with awareness features that assist the interrupter by giving them insight into the availability of the person being interrupted. The rapid adoption of such tools in the personal computing domain motivates the question of whether implementing similar techniques could be effective in more complex domains.

Interruptions in ATC-Like Environments

There are many sources of interruptions in the ATC environment such as phone calls and radio calls from other controllers or pilots. Interruptions in ATC have attracted research interest, primarily in the area of presentation of incoming interruptions. For example, Ho et al. (2004) studied the provision of information on the nature and urgency of an interruption using different modalities. Jayaraman (2011) studied multi-modal, including tactile, notification techniques in ATC contexts. However, previous work has primarily focused on generating a fundamental understanding of interruption processes using simplified or simulated ATC environments. For example in Ho et al.'s (2004) simulated ATC environment, the task associated with the interruption was constant and contrived (counting stimulus patterns) and there was no interaction with other human operators. The limits of this previous work suggests there is an opportunity to consider the practical implications and opportunities for design to manage interruptions within the existing systems and displays used in current ATC operations.

Controller-Controller Communications

In current ATC operations, there are few tools to assist air traffic controllers in managing interruptions. Co-located controllers are able to take advantage of auditory, visual, and tactile cues to gain situation awareness of each other's current tasking and gauge interruption actions accordingly. However, controllers are often communicating with other controllers located in distant buildings over telecommunication links (Figure 1).

While new technologies such as electronic flight-data strips are providing non-verbal communication channels (Allendoerfer et al, 2010), in North America controllers primarily communicate with each other verbally using telephone lines controlled by the Voice Switching Communication System (VSCS, see Figure 2). The VSCS has a tactile touch screen providing radio and telephone line access to controllers of neighboring airspace and other operational personnel. In Figure 2, the individual rectangular buttons and ovals represent controllers working other sectors with whom a controller might need to collaborate. However, existing implementations of the VSCS displays provide limited cues as to the availability of a controller being called, or how urgent an incoming call is.

Interruption Management Features to be Evaluated

The lack of interruption management features in existing implementations of the VSCS has motivated the development of prototypes to help support better interruption management between distributed controllers. Alqahtani and Histon (2012) previously described the process used to develop and prototype the Working Awareness Interruption Tool (WAIT). The tool is intended to represent a potential future modification of the VSCS screen providing support for:

1) awareness of another controller's availability to be interrupted,
2) indicating one's own availability to be interrupted,
3) awareness of an incoming call's urgency,
4) indicating the urgency of an outgoing call.

These four functionalities are illustrated in Figure 3.

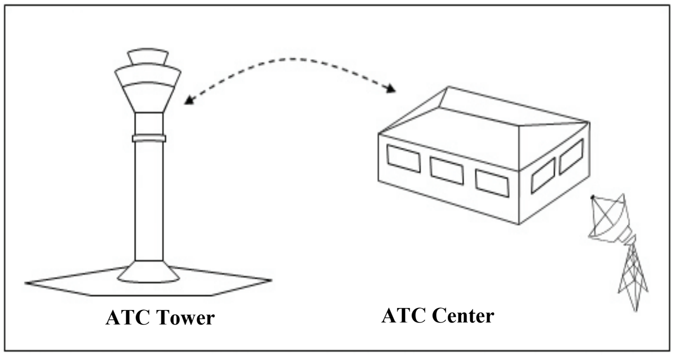

Figure 1: Example of remote communications in ATC context. (adapted from Alqahtani and Histon, 2012)

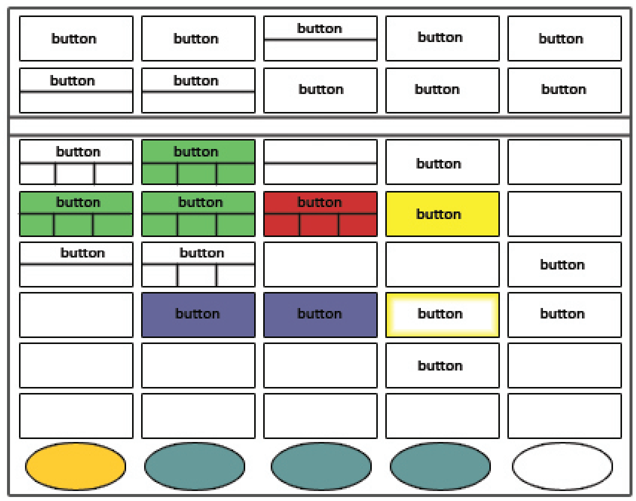

Figure 2: Graphical representation of an existing VSCS screens adapted from Transportation Safety Board of Canada (2003)

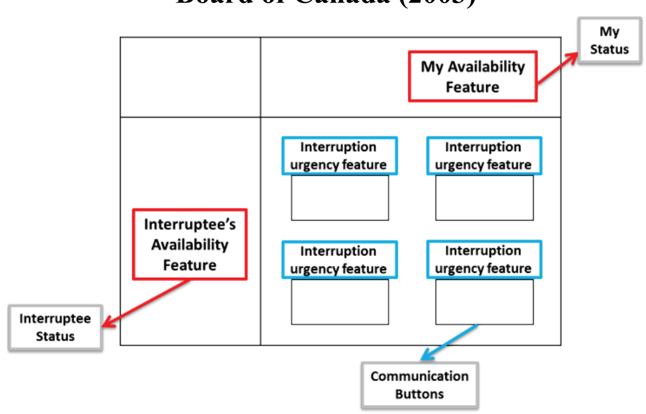

Figure 3: Feature location within the WAIT tool.

The intent was to provide a test-bed where new interruption management concepts can be tested. As such, the current design is not optimized; it is not intended to appear exactly the same as what would be expected in a production environment. The top right corner of the WAIT interface is reserved for a controller to specify his/her own availability; the left hand side is reserved for displaying the availability of a controller he/she is attempting to contact. The availability of a controller he/she is interrupting is shown on the left side only when it is solicited. The bottom right of Figure 3 shows buttons, envisioned as similar to these on standard VSCS screens, modified to provide means of conveying and observing the urgency of an interruption.

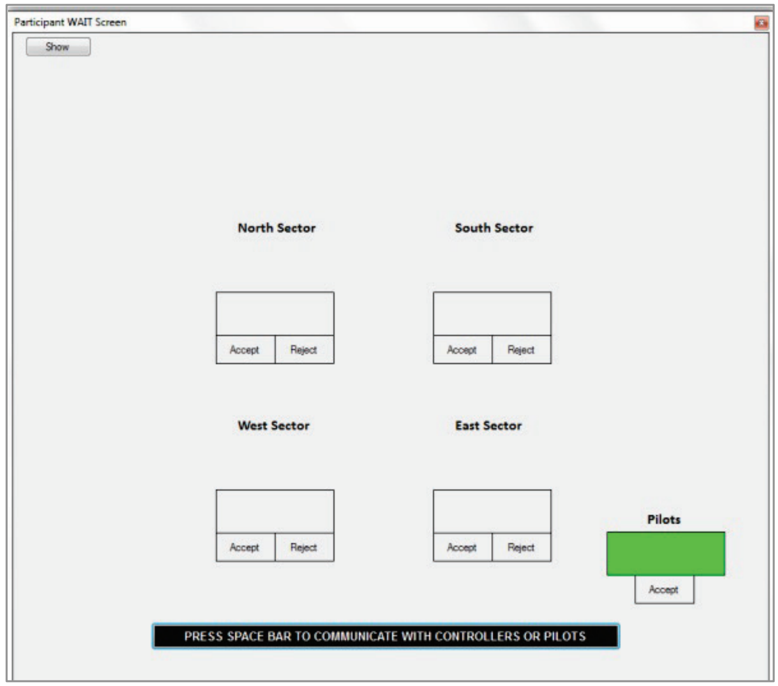

Figure 4: Baseline WAIT participant interface

Alqahtani and Histon (2012) previously described prototype implementations for a controller's willingness to accept interruptions and an ability to set the priority of an interruption. Further reflection suggested the labels (willingness and priority) did not match the intended functions. The features are designed to reflect a controllers availability (rather than willingness) and the urgency (rather than priority) of an interruption. This change in terminology is reflected in Figure 3 and the current experiment is focused on evaluating the prototype availability features as well as the ability to set the urgency of an outgoing call.

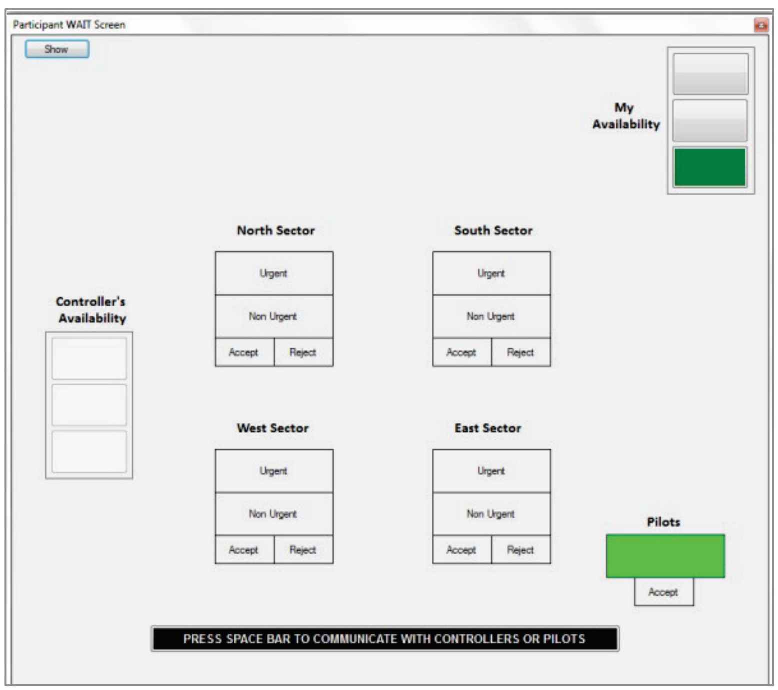

Figure 5: Manual availability set-up and automated availability WAIT participant interface

Three variants of the WAIT tool are being tested. The baseline display, Figure 4, provides no interruption awareness features. It only has four controller channels that allow the participant to communicate with other controllers in the experiment world and another channel to communicate with aircraft pilots. The "Manual Availability" display, Figure 5, has an awareness feature in the form of availability levels positioned in the top right corner of the screen. The participants can set their availability by pressing one of three buttons, green, yellow, or red, to indicate whether they are available, possibly available, or not available, respectively. This display also provides on-demand information about the availability of other controllers. When the controller wishes to call another controller, they first select a communication channel button for the respective sector (e.g. West Sector). This action causes the availability level for that controller (e.g. West Controller) to be displayed on the left side of the display. To proceed with the call, the controller re-selects the communication channel button. The communication channel button has two divisions (urgent and non-urgent), which enable the controller to convey the urgency of the interruption. Selecting the respective division indicates the intended urgency of the call; for the receiving controller, the corresponding division will be highlighted on their WAIT screen. The "Automatic Availability" display has the same appearance as the "Manual Availability" in Figure 5, but the availability is automatically determined by the number of aircraft controlled in the participant's sector.

Design of Experiment

The goal of the experiment is to examine how well the developed WAIT interface helps individuals in managing interruptions effectively. In order to create a realistic, but accessible, test environment that emulated air traffic control was developed. Within this environment, the WAIT prototypes are available on separate displays that simulated the controllers VSCS communications screen.

Overview of the Experimental Environment

An overview of the experiment setup is shown in Figure 6. The experiment is conducted in two physically separated rooms: the participant is in Room 2 at a computer with multiple monitors. One monitor shows the radar output from an ATC simulation. The ATC Radar display shows pre-set path lines that the aircraft move along. This display is non-interactive and only viewed by the participant. The second monitor shows the WAIT interface. Participants communicate with any of the surrounding sectors (North, South, East, and West) by pressing a button on the WAIT screen.

In a second room, Room 1, two experimenters are located. One is responsible for representing the controllers of surrounding airspace, interacting verbally with the participant. The second, co-experimenter, is responsible for representing the pilots in the airspace; they will interact verbally with the participant in response to his/her instructions. The co-experimenter is also responsible for implementing, through an interactive version of the ATC Radar display, any modifications to aircraft trajectories that

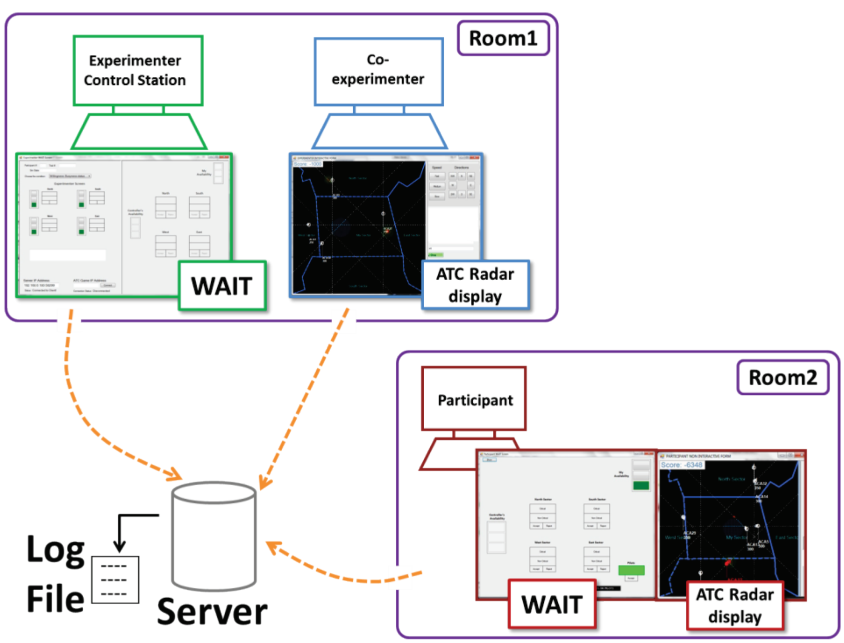

Figure 6: Experimental setup

would result from instructions given by the participant. This reduces the need for participants to learn an interface with the computer system, and minimizes necessary training time during the experiment. When a participant wants to change the direction or speed of an aircraft of any aircraft moving in the other's controllers sector areas, he/she communicates this to the controller responsible for it. The experimental crew then applies the changes (Figure 6).

Task and Scenarios

Participants complete a training session followed by three data collection sessions. In each data collection session, the WAIT tool is configured and remains in either Automated Availability, Manual Availability, or No Availability mode. The order in which participants experience the different modes of the WAIT tool is randomized across the data collection sessions in order to minimize learning effects.

The task requires participants to send and receive calls to/from controllers of other sectors and to/from pilots; the goal is to capture the essence of the collaboration between controllers in real ATC environments while still making the task simple enough to be performed without extensive training. Participants are tasked with controlling the flow of in/outbound aircrafts within the assigned sector; this sector is positioned and labeled as the "Center Sector" on the participants ATC Radar display (see Figure 6). Participants are instructed to give control instructions verbally to ensure the safe aircraft movement throughout their sector and to communicate with other controllers to coordinate responding to aircraft requests. Participants are responsible for handling aircraft "handoffs" as aircraft entered or exited the sector. Participants can obtain or provide information about other sectors or aircraft moving in the other sectors by calling "North", "South", "East", and "West" sector controllers. These calls can be to perform control tasks such as rerouting aircraft or changing speed to prevent collisions or can be associated with secondary tasks, such as collecting or providing information needed by a pilot. Similarly, participants communicate with pilots for the same reasons, but only about aircraft within the "Center Sector".

During the data collection sessions both pilots and external controllers make calls to the participant. Participants are instructed to prioritize their tasks at hand. Responding to a call is done by pressing the spacebar which opens the channel and highlights the "Accept button". If the participant is very busy and prefers to terminate the call, pressing the "Reject" button ends the call.

Data Collection

Audio and video recordings. In order to capture the verbal and physical behavior of the participants, audio and video recordings are collected. Video analysis provides insight into reasons why features are or are not effective. For example, the use of both the mouse when clicking on certain buttons and the touch screen when pressing other screen buttons can have different implications..

Questionnaire and Interview Responses. During the study, questionnaires are administered after each data collection session, as well as a final overall post-test questionnaire. Participants are also interviewed about their experiences with the tool. Both questionnaires and interviews provide rich information about the interfaces and the task scenario which helps in filling the gaps from the other data sources.

Performance Measurements. Participants' performance is captured in greater detail through subjective ratings, elicited from responses to certain questions in the questionnaires and the interview. In addition, scores are created to reflect performance on both the ATC separation task and the communication task and displayed on the ATC Radar and WAIT interfaces.

Log Files. Both the ATC Radar and WAIT interfaces provide extensive data-logging capabilities; this allows for detailed examination of participant performance in the different experimental conditions. For example, data on the time taken to respond to incoming calls can be collected for later analysis. In addition, for outgoing calls made by a participant, the availability level of the controller being called is logged. This can provide insight into how much of an effect the availability awareness features are having on participant behaviors. For example, participants may start a call to a controller who has a "Red" availability level and subsequently terminate the call before beginning to talk. Comparing how frequently this occurs in the different conditions, and whether such behavior is present at all in the baseline sessions, can provide insight into the effectiveness of the interruption tools provided by the WAIT interface.

Lessons Learned: Implications for Interruptions Research

The experimental evaluation of the WAIT prototype tools is ongoing. The following subsections discuss some of the key challenges encountered, lessons learned, and the implications for other researchers conducting similar experiments on interruption effects.

Task Design

The goal of the experiment was to begin exploring how interruption management features could be incorporated into the tools available in complex real-time collaboration environments such as air traffic control. A significant experimental design challenge was to develop a task environment that is sufficiently representative of real world operations that the results have validity, but which also provides the controls and constraints to enable researchers to experimentally manipulate the conditions and introduce interruptions in a controlled, repeatable manner.

In particular, a significant challenge was developing task environments where it would be natural for participants to want and/or need to take advantage of the interruption awareness functionality. Key to this was ensuring that interaction took place with another human, or confederate; this replicates real-world collaborative environments, where interruptions are dynamic, messy, and social. A challenge with using synthetic or computer based interruptions is the loss of social pressure on the participant; the task scenario becomes nothing more than a game with only a computer's feelings being hurt if parts of the task are ignored. By introducing the human element it is thought that more insight into participant use of tools like WAIT will be found. Using real people to act as the other communicators in the experiment creates a more realistic environment and which will influence the behavior of the participant (Sasangohar, 2009).

A second key aspect of the task design was developing realistic, context-accurate types of interruptions to create circumstances where there are obvious benefits to participant use of the tool for the task at hand. If interruptions are contrived or unrelated to the task, they risk becoming an annoyance and distraction only. This may critically miss the fact that in many cases interruptions provide benefits in the form of new or updated information that is relevant to the primary task. In the case of the current experiment, knowledge of ATC operations was used to develop plausible information requests, trajectory change requests, and other types of communications from the other controllers and pilots in the study. This represented a balance between having the ability to control the timing and type of communications that would generate an interruption, and having the interruptions be meaningful and well-integrated into the participant's task.

A third key task design decision was developing an appropriate environment for implementing the WAIT tool. There are many existing ATC simulations however none were identified that could meet the many requirements for this type of research study. The simulation needs to provide experimenters control over the traffic trajectories to assure equivalency between the level of workload and type of conflicts each participant must resolve in the different experimental conditions. In addition, most simulations require the controller to interact with mouse and keyboard to provide commands to aircraft; while ATC is moving in this direction, with the adoption of controller-pilot-data-link (CPDLC) functionality, this adds to the training complexity on the task for the non-expert participant. An ATC simulation that supports networked operations has the advantage of allowing for a co-experimenter who has been trained and is very familiar with entering keyboard commands. This in turn allows participants to simply use their voice to give commands and instructions.

Many simulations are either too simple, more akin to a game without the necessary interactivity between controllers at airspace boundaries, or too complex, requiring detailed knowledge of air traffic control procedures and operations. Finally, the simulation environment needs to have the flexibility to adapt to the experimental needs. For example, having the display area in many simulations show separate, surrounding, sectors was a significant obstacle; in addition, it is very valuable to be able to have the ability to derive certain data from the ATC simulation for logging and analysis purposes.

Interruption Design

Designing effective and repeatable interruptions is challenging. Interruption tasks should be distracting enough that they constitute a genuine disruption of a participants work. However, it is also important for data collection purposes to have the same number and type of interruptions in each experimental condition. This is particularly challenging in dynamic environments, such as ATC, where participant actions change how the traffic situation evolves. Ensuring that all participants experience exactly the same conditions is impossible.

During initial pilot tests, it was found that participants tended to lose situation awareness of the availability of other controllers. Also, sometimes, urgency levels of calls were not assigned intentionally. This indicates that the interruption tasks were extremely distracting.

This has significant implications for study design; in particular, the differences between conditions should be expected to be fairly large. Subtle, small differences between experimental conditions will be very difficult to elicit as they will tend to be masked by the large amount of noise that is inevitably introduced by unintended differences in the conditions experienced by different participants. However, as the development of interruption awareness tool is in the early stages, valuable insights can still be gained.

Training Design

An interesting challenge emerged when considering the design of the training for participants for this experiment. Given the range of functionalities, and only a single iteration with each version of the tool, a decision was made to conduct training in two distinct stages. The first stage is a general training session that introduced participants to the experimental task and explained the basic software interfaces and communication protocols. The second stage of training is focused on familiarizing participants with the specific implementation of the WAIT tool that would be used in each data collection session. This second stage training is performed prior to each data collection session. Training consists of both reference material and hands-on practice with the tools prior to data collection beginning. A PowerPoint tutorial is provided as a reference for participants during the study; in addition, they are asked to provide example commands to ensure they understand the tool functionality and are ready to begin the study.

Participants' ATC Experience

Air traffic controllers are trained to monitor their different screens periodically. Unfortunately fully trained air traffic controllers are often not available as participants, requiring the use of participants with little to no formal training or experience with ATC, particularly in the early stages of tool development. A consequence of this, identified in preliminary pilot tests, is that non-expert participants tend to focus almost solely on the ATC Radar display and to pay relatively little attention to the WAIT screen. In these cases, several important events related to the WAIT tool were missed. This process of selecting inappropriate elements of the environment and ignoring other important elements is called "selective attention" (Wickens & Hollands, 2000). The reason is that people in general get more involved in motivated contexts. In the context of the experiment, it appeared that participants were being motivated by a performance score shown in the top of the screen. While providing feedback can be valuable way of motivating participants, in this case, it appears participants become pre-occupied by the winning goal and become less concerned about using the developed new features in the WAIT screen. As a result, an additional communication scoring system was added to the WAIT screen to provide cues that would assist with attention balance. Moreover, sound alerts were added to critical communication events to enhance participants' attention to the WAIT screen.

Scenario Design

The lack of expert participant, as well as the limited time available for each experimental session, affected the type of scenarios that are used in the experiment. Creating appropriate scenarios that emulate the complex types of interruptions in the ATC environment, yet are able to be applied in the short ten minute data collection sessions, was a significant challenge. It was important to try as much as possible to ensure that differences seen in different data collection sessions reflect the different WAIT prototypes, and are not due to other unintended effects such as learning, fatigue, and/or familiarity with the sequence of events that will occur. Of particular concern was ensuring that the underlying traffic problems are similar enough that any differences seen can be attributed to the different WAIT prototypes, but different enough that participants do not 'recognize' what is coming in the second and third data collection session.

In the current experiment, scenarios were constructed by assuring that all of them have similar number of interruptions, communication timing, and aircraft traffic. In other words, they were created to have similar workload demand. This was done by utilizing a specific technique to generate multiple traffic configurations that would appear unique to the participant, but which had fundamentally similar characteristics. This was achieved by varying the initial configuration of aircraft in a symmetrical way. The first scenario was created based on the sector map and a series of flight paths that would produce a desired number of potential collisions without overwhelming a participant. The second and third scenarios were created by rotating the traffic routes first horizontally (for the second scenario) and then vertically (for the third scenario) then re-allocating the aircraft on the resulting traffic routes. This common underlying traffic configuration allowed scripts for pilot and other controller requests to be standardized across the three scenarios while the appearance of aircraft appeared novel for the participants.

Tools to Support Data Analysis

A final lesson learned is the importance of early and active consideration of the performance data that should be collected from within a simulation system. Active pre-planning of data to be logged can help prevent the loss through non-collection of important data parameters. Careful consideration should be given to what performance and behavior data would support follow up analysis of findings and insights developed from questionnaires and interviews. Establishing a good sound system that will allow for a clear recording of the experimental team and the participants voice is very important. For example, for future work, more aspects of the study might be investigated, so it would very useful for future researchers in the same topic if they have an access to all important data. Also, some data that do not have the focus of the analysis might reveal unexpected interesting results.

Summary

Developing experimental protocols to test complex phenomenon like interruptions and the WAIT tool is very challenging. A number of important design lessons have been identified, including means of ensuring scenario equivalency, requirements on the design of an effective simulation environment, and considerations for the design of training processes. Pilot testing is extremely important and provided valuable feedback on the initial WAIT prototype, and on details of the experimental design. It is hoped that the lessons learned can serve as guidelines for other researchers interested in studying communication and interruptions in complex systems such ATC.

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