Dissertations and Theses

4-2013

A Naturalistic Study of Long-term Working Memory Capacity for Meaningful Visual and Auditory Stimuli

Joseph M. Jaworski
Embry-Riddle Aeronautical University - Daytona Beach

Scholarly Commons Citation
Jaworski, Joseph M., "A Naturalistic Study of Long-term Working Memory Capacity for Meaningful Visual and Auditory Stimuli" (2013). *Dissertations and Theses*. 83.
https://commons.erau.edu/edt/83

A NATURALISTIC STUDY OF LONG-TERM WORKING MEMORY CAPACITY FOR MEANINGFUL VISUAL AND AUDITORY STIMULI

by

Joseph M. Jaworski

A Thesis Submitted to the College of Arts and Sciences
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Human Factors and Systems

Embry-Riddle Aeronautical University
Daytona Beach, Florida
April 2013

A NATURALISTIC STUDY OF LONG-TERM WORKING MEMORY CAPACITY FOR MEANINGFUL VISUAL AND AUDITORY STIMULI

by

Joseph M. Jaworski

This Thesis was prepared under the direction of the candidate's Thesis Committee Chair, Dr. Kelly Neville, Associate Professor, Daytona Beach Campus; and Thesis Committee Members Dr. John Wise, Professor, Daytona Beach Campus; Mr. Randall Triplett, Assistant Professor, Daytona Beach Campus; and Dr. Tina Frederick-Recascino, Professor, Daytona Beach Campus
and
has been approved by the Thesis Committee. It was submitted to the
College of Arts and Sciences in partial fulfillment
of the requirements for the degree of
Master of Science in Human Factors and Systems

Thesis Committee:

Kelly Neville
Kelly Neville, Ph.D.
Committee Chair

John Wise
John Wise, Ph.D.
Committee Member

Randall Triplett
Randall Triplett, M.S.
Committee Member

Tina Frederick-Recascino
Tina Frederick-Recascino, Ph.D.
Committee Member

Scott Shappell
Scott Shappell, Ph.D.
Department Chair, Human Factors and Systems

William Grams
William Grams, Ph.D.
Dean, College of Arts and Sciences

Robert Oxley, Ph.D.
Associate Vice President of Academics

Date 5-15-2013

Acknowledgements

I would like to thank the many people that have both assisted me in the writing of this thesis and also the many people that have supported me in this endeavor. First, I would like to thank my committee chair Dr. Kelly Neville for always encouraging me to reach further than I thought possible and for encouraging me to always put my best foot forward. Under your guidance I have learned so much and you have prepared me to take on any challenge that may come my way. I would also like to thank my committee members Randy Triplett, Dr. John Wise, and Dr. Christina Frederick-Recascino. Your continued support and knowledge has taught me so much and I have enjoyed working with every single one of you. To my friends, thank you from the bottom of my heart for being the support structure that has gotten me through the tough days, but also has been there to celebrate the good days along the way. To my family, thank you not only for your support throughout my thesis but through my entire college career. Mom, Dad, Niki, and Jena, without your continued love I would not be where I am now and would not be the person I am today. Alyssa and Taylor, my beautiful nieces, your voices could make any day brighter and those phone calls just to say “I love you” was the best support I could get. To my boyfriend, Erik, thank you for being the strength when I thought I had no more and for always being there to listen. Your love and encouragement has guided me along the way and I could not be where I am without you.

Abstract

Researcher: Joseph M. Jaworski

Title: A NATURALISTIC STUDY OF LONG-TERM WORKING MEMORY CAPACITY FOR MEANINGFUL VISUAL AND AUDITORY STIMULI

Institution: Embry-Riddle Aeronautical University

Degree: Master of Science Human Factors and Systems

Year: 2013

The purpose of this study was to explore long-term working memory in experts in an information-rich, dynamic domain. Of particular interest were strategies experts use to enhance long-term working memory capacity when working with verbal versus aural information. Three air traffic control instructors participated in four complex air traffic control scenarios, two radar scenarios in which information was presented visually and two non-radar scenarios in which information presentation was purely aural. Participants recalled traffic situation information at two points during and at the end of each scenario. Recall data for each scenario type were assessed in terms of evidence about information *chunking* and organizational strategies, the role of long-term working memory in extending working memory capacity, and the format of traffic situation information held in long-term working memory. Patterns of recall were consistent with template-based explanations of information organization and the use of information chunking within templates. Data were consistent with Ericsson and Kintsch's (1995) model of long-term working memory in that working memory capacity seemed to be extended by the storing of traffic situation information in long-term working memory templates from which it seemed to be selectively and readily accessed and brought into working memory. Traffic situation information tended to be recalled in different orders for radar compared with non-radar scenarios, although the general organizational structure of the information seemed similar. Information, regardless of whether presented visually or aurally, tended to be recalled based on aircraft position, which seemed to prime other aircraft attributes which, in turn, seemed to prime yet other aircraft attributes. The results of this research have the potential to contribute to the long-term working memory, working memory, and expertise literatures. For example, they suggest hypotheses about expert and novice long-term working memory capacity that could be pursued in future research. To this end, the present study will be replicated using novice air traffic controllers. The comparison of novice and expert recall patterns has the potential to shed light on differences in information storage and recall strategies and could have implications for training air traffic controllers. The study additionally could hold implications for the design of NextGen air traffic control products and systems in other complex work domains. These results could shed light on display design for those systems by suggesting which information can or should be displayed within an aircraft's data tag and which can or should be presented aurally.

Table of Contents

List of Tables

List of Figures

Introduction

Working memory

Working memory refers to the conceptual storage area where information is held while being actively processed. One of the most actively pursued working memory research topics has been the question of working memory capacity – how much information can be held in working memory at one time? Research and theory addressing this question and related questions about factors and processes hypothesized as influencing working memory capacity will be described in the paragraphs that follow.

Researchers have sought to characterize working memory capacity in two primary ways, in terms of a pure capacity limit and the limit on the storage of meaningful stimuli (e.g. Cowan, 2000). Miller (1956) reviewed absolute judgment experiments and used their results to develop his hypothesis that the number seven represents the pure human information processing (i.e. working memory) capacity or, more specifically, Miller characterized the capacity limit as seven plus or minus two *chunks,* which he described as consisting of interrelated *bits* of information. Miller describes how one can combine bits of information to produce a chunk; also known as information *recoding.* According to Miller, chunking consists of "organizing bits of information into familiar units…since memory span is a fixed number of chunks, we can increase the number of bits of information that it contains simply by building larger and larger chunks, each one containing more information than before" (p. 91). Miller suggested that humans use this chunking strategy to increase the amount of information that can be processed at one time. An example he provides is when there is an idea, story, or part of a speech that we want to remember, we tend to put it "in our own words" (p. 92). In addition, Miller describes an unpublished study by Sidney Smith in which participants' memory span for (i.e., recall of) binary digits increased incrementally as the size of the chunks they were instructed and trained to derive increased. This way of chunking assists us in expanding working memory capacity.

It cannot be said that capacity in working memory can be described in one simple way; rather, it tends to vary depending on the stimuli. Miller hypothesized that stimuli and chunks differ in the amount of information they hold and those differences result in memory span differences constrained by a pure capacity limit of seven plus or minus two chunks. He notes in his article that findings by Hayes (1952) do not, however, support a one-to-one relationship between amount of information held and number of stimuli (or chunks) recalled. In Hayes' study, increases in the amount of information held in a stimulus did not lead to equal decreases in the number of stimuli recalled. Miller accommodates that finding by concluding that the amount of information held in a stimulus is less than the amount transmitted and that the effect of information increases was therefore somewhat muted in Hayes' research. Subsequent research on working memory capacity has revealed a more influential factor than information content, however: whether or not a stimulus is construed as meaningful or familiar by the person perceiving it. Work by Chase and Simon (1973) to be described below is among this body of research.

Chase and Simon (1973) built on Miller's work by comparing working memory capacity in experts and novices. Specifically, Chase and Simon studied chess experts and novices to "discover and characterize the structures, or chunks, that are seen on the board and stored in working memory" (p. 56). To do so, Chase and Simon compared expert and novice memory for meaningful and non-meaningful stimuli, i.e., for chess pieces in game-play chessboard configurations and chess pieces in impossible chessboard configurations.

Participants performed two tasks, which Chase and Simon refer to as perception and memory tasks. In the perception task, expert, mid-level, and novice chess players were asked to copy a chessboard configuration on an empty board while glancing at the source board as infrequently as possible. In the memory task, players viewed a chessboard for five seconds and then tried to recreate the board's configuration on a blank board. The results indicated that experts recreated the chessboard configuration almost perfectly in the memory task, and correctly placed many more chess pieces than mid-level or novice players. In the perception task, the authors identified chunks of chess pieces by noting each glance taken of the chessboard configuration and each pause of more than two seconds in the recreation process. They found that chunk size for meaningful stimuli was smaller in the low experience groups.

Thus, the results indicated that for the impossible chessboard configurations, expertise played no role in recall. There was no difference in the number of chess pieces recalled or chunk size. There was a difference in the recall of meaningful board configurations however. In the perception task, experts' recall of meaningful mid-game and end-game chessboard configurations averaged 7.7 chess pieces per chunk, master's averaged 5.7 chess pieces per chunk, and beginners' averaged 5.5 chess pieces per chunk.

Based on a review of decades of research including much like the seminal work of Chase and Simon, Cowan (2000) suggests that Miller's 1956 estimate of chunk size inflates the pure storage capacity of working memory. He argues that the capacity is closer to three to five chunks. Cowan suggests the capacity of seven plus or minus two is still valid when material is being processed strategically, e.g. by means of rehearsal, chunking, and memorization (Cowan, 2000); however, the pure capacity limit for the focus of attention seems more likely to be three- to five chunks.

Gobet and Simon (2008) challenge Cowan's assessment of the pure storage capacity of working memory, claiming that it may be an overestimate and that working memory capacity is closer to three or even two chunks. Gobet and Simon (2008) compared two theories: *template theory,* which suggests a working memory capacity of around four templates (Gobet & Simon, 1996), and the *chunking theory,* which suggests an overall working memory capacity of around seven chunks (Miller, 1956). The subjects, six novices, four mid-level players and three master chess players, were asked to complete three tasks. The first was the *copy task*. This was the same as Chase and Simon's (1973) perception task except performed on a computer display. The *recall task* was the same as Chase and Simon's memory task, performed on a computer. Finally, the third task was a *partitioning task* where subjects were asked to group pieces in a way that made sense to them. This experiment was designed to examine whether the findings of Chase and Simon were affected by the physical limit on the number of chess pieces that could be held in the subject's hand. The number of pieces the subject was able to pick up to place at one may have artificially limited assessed chunk size in that study.

The recall task results of Gobet and Simon indicated that when it comes to chunking, it is not the number of chunks, or *templates* as they called the meaningfully combined sets of information, that varies with player skill level, but more likely it is the size of the templates. In the recall task, the players averaged a template recall of around three and closer to two; however, the size of the chunks increased with experience, sometimes reaching 15 pieces per chunk in one of the master's recall. These findings were for computer chess whereas for the traditional board game version, the pieces per chunk were 4.5 for mid-level players and 4.8 for experts (Gobet & Clarkson, 2008). These results indicated that, in fact, the chunk size limits found by Chase and Simon were likely due to physical limitations on how many pieces could be held at one time.

Taken at face value, the results of this study suggest that there is still no clear resolution about the number of chunks or templates that can be held in working memory. However, what does seem clear is that Miller's original seven-chunk limit seems to be a mischaracterization of working memory capacity and structure; with recent studies suggesting fewer chunks but more sophisticated chunks that may store within them much more than originally thought.

Long-Term Working Memory

Now that working memory has been covered, I will briefly discuss an area of study that focuses on the newer concept of *long-term working memory*. This concept was introduced by Ericsson and Kintsch (1995) to explain evidence suggestive of an expanded capacity in working memory that allows people – especially experts – to actively process and work with a great deal more information than should be possible in light of the majority of research findings about the capacity of working memory. This expanded capacity may reflect the use of long-term memory to keep relevant information readily available to working memory, i.e. a portion of long-term memory may serve an extension of, or be co-opted by, working memory.

According to Ericsson and Kintsch (2002), the use of long-term memory as an extension of working memory, i.e., the use of long-term working memory, is only possible for those who are able to rapidly store information in long-term memory. This ability develops with experience working with and the acquisition of knowledge related to the particular type of information being presented. When these prerequisites are adequate, Ericsson and Kintsch argue that long term memory should contain a knowledge structure that will support selective and rapid information retrieval—information retrieval that is rapid and agile enough so as to seem it is held continuously in working memory when it actually is shuttling back and forth between working and long term memory, e.g., to support the handling of a large information load. Rapid information retrieval by experts is said to depend on the encoding of information in long term memory with retrieval cues. When many of these cues are organized into a coherent set, Ericsson and Kintsch refer to these as retrieval structures. These structures are composed of cues, which make the encoded information accessible, or available to working memory, Information that is active in working memory will trigger a retrieval cue and retrieval structure, activating the connected knowledge such that it is readily available for use in working memory. Figure 1 shows Ericsson and Kintsch's conceptualization of long-term working memory as a retrieval structure where the information stored in LTM is associated with retrieval cues. In summary, Ericsson and Kintsch's long-term working memory construct explains how storing domain-specific information in an accessible form in long-term working memory can expand working memory capacity.

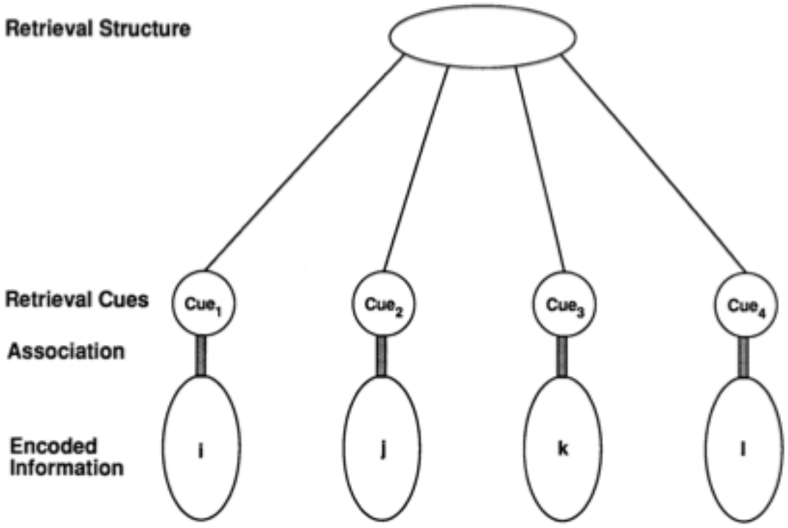


Figure 1. This diagram is the base model of what Ericsson and Kintsch think the retrieval structure would look like. As the diagram portrays, retrieval cues "trigger" the activation of information associated with them. Adapted from "Long-term working memory" by K. A. Ericsson and W. Kintsch, 1995, *Psychological Review,* p. 10.

Sohn and Doane (2004) studied the role of long-term working memory in complex cognitive task performance. Specifically, they looked at performance in an aviation task and the effects working memory (working memory) capacity had on task performance. Three tasks were performed: a span task, a situation recall task, and a situation awareness task. The span task was used to assess working memory capacity. The situation recall task was used to test long-term working memory. Both the scan and situation recall tasks were used to assess the relative role of working memory and long-term working memory in the situation awareness of novices and experts.

The span task consisted of spatial and verbal format. For the spatial portion, participants were presented with capital English letters and their mirror image. The letters were presented one at a time and in different orientations (45 degree increments) for 2200 ms each. The participants were asked to verbally report whether the orientation of each letter was the normal or mirror image as quickly and accurately as possible. After the presentation of a series of two to five letters (selected from a set of five letters), participants were asked to recall their orientations in order by clicking on corresponding buttons that were indicative of the different orientations. The verbal span task was identical to that of the spatial task, however two additional letters were added to the letter set and participants were asked to recall each series of letters by typing them on a keyboard.

In the situation recall task, novice and expert pilots were asked to view two cockpit displays, one above the other, representing display states that either could or could not appear consecutively during a flight, for a total of 40 s each. The displays were either pictorial cockpit snapshots or verbal lists of aircraft indicators and readings and, as in Chase and Simons' (1973) chess study, flight information was displayed in either both meaningful or impossible combinations (i.e., in pairs that could or could not occur consecutively). After cockpit display presentation, the pilots were asked to perform a distraction task for 30 seconds. After the distraction task, participants were asked to recall one of the two cockpit displays on a sheet of paper.

Lastly, in the situation awareness task participants viewed a goal screen and two consecutive cockpit displays where they would have to determine whether an aircraft depicted by the two cockpit displays could reach the situation in the goal display within the next five seconds.

The results of this study suggested that when comparing long-term working memory to working memory task performance, working memory task performance had less of a relationship with situation awareness then did long-term working memory task performance. Experts' long-term working memory scores, but not their working memory scores, were higher than novices'. The results support the notion that long-term working memory supports expert performance and overcomes differences in working memory capacity. The results suggest that the higher the expertise, the greater the role of long-term working memory. This allows the expert performer to rely less on working memory capacity alone.

Visual versus Spatial Working Memory

It has been hypothesized that within working memory there are separate resources to process different modalities of information (e.g. Shah & Miyake, 1996). Baddeley and Hitch's (1974) model of working memory presents separate storage areas for auditory and visual information - the *phonological loop* and *the visuospatial sketchpad*, respectively.

The core of working memory was thought to have a limited capacity, which was referred to as a "workspace" (Baddeley & Hitch, 1974). From that, however, Baddeley and Hitch suggest that as illustrated in Figure 2, working memory is divided into three separate parts. Each of these parts would be used to process, transfer, and store different kinds of information. The three parts of working memory proposed by Baddeley and Hitch, are: the *central executive*, the visuospatial sketchpad, and the phonological loop. This model specifies different resources for processing verbal and visual information; consistent with research suggesting the two forms of information can be processed at the same time without interfering with each other (e.g., Lehnert & Zimmer, 2006; Shah & Miyake, 1996)

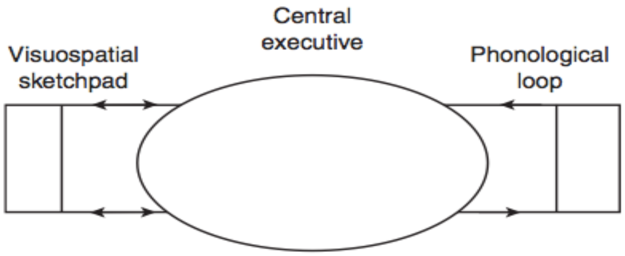


*Figure 2***.** This diagram shows the components of working memory. “The development of working memory in children” by L. Henry, 2012, *The Development of Working Memory in Children,* p. 4.

The central executive in Baddeley and Hitch’s working memory model is the “dictator” of the entire system and is in charge of directing information to the visuospatial sketchpad or phonological loop. The central executive also determines the priority of information. In addition, the central executive considers whether or not the other working memory elements should relate their contents to long-term memory.

The visuospatial sketchpad is, as the name indicates, the area where visual images and spatial information are processed. This component interacts with long-term memory and is involved in the storage and recall of pictorial information and mental imagery. For example, if a question was posed about how many stoplights one passes on one’s daily route to work, one might attempt to visualize that route and count the number of stoplights. Picturing the route makes use of the sketchpad.

The phonological loop, which deals specifically with spoken and written verbal material, functions in parallel with the visuospatial sketchpad and has the following elements:

- *The Phonological Store* is an area within the phonological loop system that can store speech-based information for 1-2 seconds. The information in this store takes a verb foralm and thus written material must be converted into spoken code before it can be stored.
- *The Articulatory Rehearsal Process* is a process within the phonological loop system that supports speech-based repetition of information in order to maintain it in working memory. This is the process within working memory whereby we rehearse, for example, information we are trying to commit to long-term memory, such as an amount of money, an address, or a student identification number.

Baddeley and Hitch's model replaced the view of a passive short-term memory store connected to a long-term memory store. In the place of a passive short-term memory, their model proposes a system of multiple active processes for storing and retrieving information. This piece of work created a new way of considering the capabilities of memory, and suggested new lines of empirical inquiry.

One line of inquiry involves studying differences in the storage and retrieval of verbal compared with visuospatial information. A closely related and arguably overlapping line of inquiry focuses on memory differenced associated with auditory and visual information. For example, research conducted in a controlled laboratory setting by Craik (1969) suggested that auditory information is better recalled than visual. This was the finding of a study in which a subject was asked to recall stimuli from a particular half of a list of either aurally or visually presented items. Thus, a participant might be asked to recall the items from the end of a given list. Each combination of information type and list half (i.e. visual-beginning, visual-end, auditory-beginning, and auditory-end) was analyzed. A difference was found in the recall of end-of-list information in both input modalities when compared to recall of beginning-of-list information in both modalities. In a subsequent, between-subjects design, results yielded a slight advantage for the last items in lists presented in the auditory mode compared to visual mode. This effect was attributed to echoic memory. These results, taken together, suggest that input modality does not seem to have an effect on working memory capacity, at least not when studied in a laboratory setting using generic study materials.

Lehnert and Zimmer (2006) looked into whether a modality-specific spatial memory system exists. Within the visuospatial sketchpad there is a *visual cache* where visual spatial information is temporarily stored (Logie, 1995, as cited in Lehnert & Zimmer, 2006). Lehnert and Zimmer wanted to determine whether auditory spatial information is stored in the same or a different cache. Experiment 1 consisted of 40 matched pictures and sounds (i.e. picture of a dog [visual] and sound of dog barking [auditory]). Mixed and pure modality stimulus sets were presented in sets of four, six, and eight. During the study phase, the stimuli of a given set were sequentially presented, each appearing in one of four display locations. After a short interval, two test stimuli from the just-studied list appeared sequentially in the center of the display. The subjects were instructed to indicate the location in which each test stimulus had appeared using keys mapped to the four display locations. The researchers found that as set size increased, location-recall performance decreased, as would be expected if working memory capacity is limited. Of central interest, no benefit of mixed over pure modality list was observed. This suggests that within working memory there is a common store for auditory and visual spatial information, a finding that was upheld by Experiments 2 and 3.

Further evidence related to information format effects on memory can be found in dual-task performance research. In a study by Cocchini, Logie, Sala, and MacPherson (2002), participants performed three tasks: serial digit recall, visual pattern recall, and a perceptuomotor tracking task [Experiment 1] or articulatory suppression task [Experiment 2]. Each of the three tasks was first performed individually and the two recall tasks were performed individually under immediate and 15-s delayed recall conditions. This was followed by dual-task performance. In two of four dual-task between-subjects conditions, the stimuli for the serial digit recall task were presented, i.e., *preloaded*, followed by 15 s of performing the visual pattern recall task, a visual memory task (in the Digits + Patterns condition) or by 15 s of performing the perceptuomotor tracking task [Experiment 1; in the Digits + Tracking condition] or articulatory suppression task [Experiment 2; in the Digits + Suppression condition], after which the digit recall task stimuli were recalled. In the other two dual-task conditions, stimuli for the visual pattern recall task were presented, followed by 15 s of performing the serial digit recall task (in the Patterns + Digits condition) and of performing either the perceptuomotor tracking task [Experiment 1; in the Patterns + Tracking condition] or articulatory suppression task [Experiment 2; in the Patterns + Suppression condition], after which the visual pattern stimuli were recalled. Visual pattern and digit recall during the 15-s increments was considered *immediate recall*. Recall of the preloaded pattern or digit set was considered *delayed recall*.

The findings of Experiment 1 pointed toward a multi-component working memory system. Specifically, although dual-task performance was impaired in some conditions, the researchers found that, at least in delayed-recall conditions, two very demanding memory tasks (serial digit recall and visual pattern recall) could be performed concurrently with minimal interruption. (Although, it is worth noting that the lack of a training period means that the comparison of single and dual task conditions is likely at least partly confounded with learning effects.) Experiment 2 was conducted to determine if the immunity to dual-task performance observed for delayed recall conditions in Experiment 1 could be explained by retention of the preloaded stimuli in long-term memory. Cocchini et al. used an articulatory suppression task in lieu of continuous tracking in order to prevent stimuli from being stored in long term memory and still found that under delayed-recall conditions (only), an impact of articulatory suppression on the delayed recall of digits but not of visual patterns, suggesting that the digit recall task preload had been retained in the phonological loop of working memory in Experiment 1. In contrast, the visual pattern preload (i.e., visual pattern delayed recall) was not affected by the intermediary task, calling into question, according to the authors, dual-task interference effects found in Experiment 1. Thus, although these researchers did not find strong effects, they argue that their evidence supports the existence of multiple working memory systems for storing and processing different forms of information.

The results of the three studies reviewed above show mixed-support for modality-specific working memory storage areas. Nonetheless, a consistent advantage for the recall of visual imagery over other types of stimuli has been observed, including by Lehnert and Zimmer. Further, information format may have an effect on the extent to which long-term working memory is able to support and extend working memory. Sohn and Doane’s (2004) study, for example, includes the finding that experts’ recall advantage over novices for meaningful flight status values only held for the pictorial presentation of values, not the verbal presentation.

Goals of the Present Research

The current study is aimed at exploring experts' working memory capacity and memory strategies for storing and recalling aurally and visually presented information in their domain of expertise, air traffic control. In particular, the following areas of interest were examined:

- whether there tends to be a difference in experts' recall of information presented in visuospatioal versus auditory format, even though both forms of information may be used to support a visuospatial representation of the air traffic situation;
- whether patterns of experts' recall and associated storage structures or memory strategies differ for verbally versus aurally presented information;
- whether long-term working memory seems to enhance working memory capacity and, if so, how; and
- whether the experts seem to use chunking information and, if so, the size and number of chunks recalled.

Method

Participants

Three male retired air traffic controllers working as ATC instructors were volunteers in this study. Each participant took part in four 28-minute scenarios. Two were professors in the air traffic control department at Embry-Riddle Aeronautical University (ERAU), one was an ERAU lab instructor. They were retired Certified Professional Controllers (CPCs) with 23 to 34 years of experience controlling (M= 27) and had been retired for between 10 and 23 years (M= 18). The participants had an average of seven years experience teaching or lab instructing at Embry-Riddle. Participants were given a biographical survey (see Appendix A) upon arrival, which in addition to the information above, asked for the facility types (Tower, TRACON, and En Route) they have worked in, the highest-level facility at which they have worked, and the highest position beyond CPC they have held. Participants were briefed on the purpose of the study upon completion of their participation. Before beginning they were asked to read and sign a participation consent form (see Appendix B) and an audio/video recording consent form (see Appendix C), and were informed that they were free to end their participation at any time.

Experimental Design

The experiment was a two-level within subjects design. The independent variable was Control Mode (Radar vs. Non-Radar). In each condition the participant performed two scenarios. The four scenarios were matched for difficulty and presented in an order that was counterbalanced utilizing a balanced Latin square.

Facility

The experiment was conducted in the En Route Air Traffic Control Lab at ERAU. The FAA has certified these labs as official training labs. Students completing their degrees in Air Traffic Management use these labs. Each participant sat at a standard air traffic control workstation equipped with two vertically stacked 20-in. Dell computer monitors, a standard Dell computer keyboard, a data entry keyboard, a trackball mouse, a set of headphones with microphone attachment, a foot pedal and hand-activated control for push-to -talk communication, and, to the right of the displays, two flight strip bays for stacking flight strips. The lighting in the room was dim. The lower of the two monitors is the radar display. The upper monitor displays meteorological information, flow control information, and active military operating areas.

Confederates

In each scenario, a pseudo pilot sat at a pseudo pilot workstation on the opposite side of the lab from the participant and behind a divider. The pseudo pilot voiced communications for the pilots of all simulated aircraft in the scenario and controlled the aircraft by inputting all aircraft instructions given to pilots by the expert controllers. Pseudo pilot communication to controller was scripted; it appeared in a prompt box when the pseudo pilot clicked on each aircraft. The pseudo pilot was instructed to give no additional information before, during, or after the testing. The pseudo pilots were student laboratory assistants paid by the Air Traffic Control Department at ERAU who have completed the Non-Radar class. A single pseudo pilot supported all participants across all four scenarios. The pseudo pilot workstation includes a 20-in. computer monitor, a standard Dell keyboard, and a pair of headset/microphone headphones. A foot pedal and hand-activated control for push-to-talk communication activated communication.

In the Radar condition, a Data Controller (known as the *D-Side controller*) sat to the right of the participant. His purpose was to sequence flight strips according to arrival time for the Radar controller. This D-side role is standard in everyday air traffic control operations and he did not support the participant in any other way. This confederate controller had the same equipment as the primary controller.

Two assistants aided the experimenter. A master plan for conducting the experiment (see Appendix D) was developed by the experimenter and used by the experimenter and both assistants during the conduct of the study. As specified in the master plan, Assistant 1 was responsible for the pausing of the scenarios at the appropriate times. During each pause, Assistant 1 was responsible for taking a screenshot of the paused traffic situation from the pseudo pilot console and saving it to an external disk. The instructions for Assistant 1 can be found in Appendix E. Assistant 2 was responsible for the distribution and collection of the blank sector map. On cue of the experimenter, Assistant 2 would turn off the display monitor and place a blank sector map in front of the participant. At the end of each recall period, or after the participant indicated they were finished with the recall task, Assistant 2 removed the map, turned the monitor back on, and filed the map according to scenario and pause. Assistant 2 instructions are found in Appendix F.

Materials

Blank sector maps. A blank sector map (See Appendix G) was shown to the participant during traffic situation recall trials to facilitate recall. The sector map included airspace markings (e.g., route information such as victor airways), boundary lines, fixes (i.e., specific positions within the airspace), and airport markers.

Flight strips. Controllers used flight strips during all scenarios just as they would use them on the job. Flight strips are legal documents controllers use to track each flight by inputting aircraft information (e.g. call-in time, altitude, next fix) and were used in this experiment to optimize the realism of the ATC setting. The implication of their status as legal documents is that the controller is required (as part of his or her duties) to maintain them with up-to-date information.

Audio/Video recorder. Two audio/video recorders were utilized to capture participants' recall of airspace information. The devices were set up over the left and right shoulder of the controller and showed the monitor within the field of view. The purpose of the second recording device was to serve as a back up.

Scenarios. Using the NextSim scenario development software, four 28-minute scenarios—two radar and two non-radar—were created for this study. Scenarios were defined loosely in terms of route complexity within a given area of operations. NextSim characterizes all scenarios on a level 1-10 difficulty and characterized each scenario used for this study as level-10 difficulty. Difficulty is not determined by the number of aircraft but by the complexity of routes in a scenario. Non-radar control is more difficult than radar control, and the NextSim difficulty assessment algorithm takes this into account. The airspace used for these scenarios was Memphis Center (ZME) in Memphis, TN.

Procedure

The participants were told they would be asked to perform four scenarios and were instructed to control traffic as they normally would. They were informed that each scenario was going to be paused twice and that at each pause and at the scenario's end they were to recall the current traffic situation and the characteristics of each flight immediately. Participants were told that each time the scenario pauses or ends, the display would go blank, a blank sector map would be placed in front of them, and they should immediately begin recalling. The following recall instructions were read by a researcher: "In no particular order, please recall the current traffic situation including items such as: a/c identification, speed, altitude, direction of flight, hand/offs upcoming and past, point outs, arrivals, departures, conflicts." Each recall had a time limit of four minutes.

The participants were informed that their recall trials and control performance would be videotaped. The video camera was focused on the computer screen at an angle over the non-dominant shoulder to capture the movement of the controller's hand in case he pointed to the blank sector map during recall and also to capture the display right before each recall trial.

After being familiarized with the study's procedure, the participants were handed a set of flight strips and instructed to begin as soon as they were ready. The scenario and data collection then proceeded as described in the participant instructions above with the exception of pre-planning performed in the Non-Radar condition. Scenario pauses occurred at times that were randomly selected from within the windows of 8-12 minutes and 16-20 minutes (See times listed in Appendix H).

Each scenario in the Non-Radar condition began with a preplanning period of 12 minutes. Using the preplanning guide (Appendices I and J) that is specific to ZME, the participant was able to visualize boundary crossing restrictions, inappropriate altitude for direction of flight (IAFDOF; i.e., the aircraft is too high or too low for the route it is assigned to), holding patterns, and route conflicts. As any or all of these constraints were found to be relevant to a given flight, the controller marked them appropriately on that flight's flight strip.

A method used to assist experts in verbalizing cognitive work is the verbal retrospective think-aloud protocol. At the end of each participant's last scenario, the participant was asked to verbally walk-through (recount) his most recent recall trial and to recount the "how" and "why" of the recall process to the extent able. The response was videotaped.

Data Analysis

Traffic situation recall. Videotaped recall sessions were reviewed and the recalled details were transcribed. The traffic situation corresponding to each recall session was captured by individually reviewing the order in which details were recalled and searching for any patterns in recall order across all six trials per condition.

The types of aircraft details recalled, patterns in recall, and the average number of details recalled was assessed for domain expert memory and to determine if differenced tended to exist between the Radar and Non-Radar conditions.

Retrospective think-aloud data. Retrospective think-aloud data were transcribed and coded (categorized) to characterize responses as implicating the use of either the visuospatial sketchpad or the phonological loop to process traffic situation information. Each data extract in each transcript was assessed by two independent coders to determine whether it referred to the processing or recall of visuospatial information, verbal information or neither and each was coded accordingly. The two coders were a graduate student who is the author of this thesis and an instructor of college-level psychology classes. Through a discussion of conflicting codes, code reconciliation was achieved. Cohen's Kappa was used to measure the level of agreement between the two coders prior to reconciliation.

Validity and Reliability

The multiple data collection and assessment methods used in this study helped the researcher to gauge the consistency and thus the validity of the evidence. In addition, the use of two different scenarios for each condition improves the validity of the findings. Results are reported in terms of patterns observed accompanied by the descriptive statistics and raw data (e.g., experts' quotes from the think-aloud protocol) that support them.

Results

Recall data were reviewed to find total the number of aircraft accurately recalled across the six recall trials in each condition. (See recall data organized by expert and scenario in Appendix K.) Table 1 and Table 2 show the number of aircraft recalled by condition and expert. The tables show that more aircraft tended to be recalled in the radar compared with the non-radar condition. These recall values only represent a partial picture of what the controllers could recall. The paragraphs that follow describe the additional recall of attributes of these aircraft and patterns in their recall that may have implications for recall strategies used, working memory capacity, and the relationship of working and long-term memory.

Table 1

Average Number and Percent of Aircraft Recalled Across the Six Recall Trials in the Radar Condition

Expert	Mean	Standard Deviation	Percentage
Expert 1	7.33	1.97	83%
Expert 2	6.50	1.87	91%
Expert 3	5.80	1.47	71%

Note. The number of aircraft recalled is influenced by factors such as the number of aircraft in the airspace at a given pause time and the number of aircraft that are active versus inactive.

Table 2

Average Number and Percent of Aircraft Recalled Across the Six Recall Trials in the Non-Radar Condition

Expert	Mean	Standard Deviation	Percentage
Expert 1	5.33	2.25	72%
Expert 2	4.50	1.52	69%
Expert 3	3.5	.83	60%

Note. The number of aircraft recalled is influenced by factors such as the number of aircraft in the airspace at a given pause time and the number of aircraft that are active versus inactive.

Recall of Aircraft Characteristics

Aircraft location recall order was compared across recall trials, control conditions, and experts. No patterns were found; however, the researcher observed evidence to suggest a recency effect. The researcher observed that in many trails, the participant first recalled the most recent aircraft he had communicated with; however, communications transcripts were not available to allow the investigation of the potential pattern.

Recall data were further reviewed to determine what aircraft characteristics were recalled for each recalled aircraft, by condition and expert (See Appendix L). Table 3 and Table 4 show the percentages of recalled aircraft for which each of five aircraft characteristics were recalled.

Included in these tables are the data tag elements speed and altitude, but no other data tag elements because experts never recalled the latter elements (the data tag is the information located on the radar scope, next to the aircraft blip on the radar which describes information pertaining to that aircraft. This information not only includes data tag and speed, but also includes type of aircraft, destination, and aircraft call sign). In fact, no other aircraft characteristics were recalled for any aircraft. The action information recalled calculated does not describe the accuracy of assigned action recall, as the information was not available to the researcher to calculate the accuracy of assigned action recall.

Table 3

Percent of Aircraft Characteristics Recalled Across the Six Recall Trials in the Radar Condition

	Location	Call Sign	Data Tag: Altitude	Data Tag: Speed	Assigned Action
Expert 1	100%	100%	100%	27%	59%
Expert 2	100%	100%	100%	0%	48%
Expert 3	88%	73%	78%	15%	58%

Table 4

Percent of Aircraft Characteristics Recalled Across the Six Recall Trials in the Non-Radar Condition

	Location	Call Sign	Data Tag Altitude	Data Tag Speed	Assigned Action
Expert 1	100%	100%	88%	0%	78%
Expert 2	100%	100%	74%	0%	52%
Expert 3	100%	95%	95%	0%	100%

Column 5 in Tables 3 and 4 shows the percentage of times an action element was recalled. If an aircraft was not performing a controller-assigned action at the time of recall, there was no assigned action to recall; hence relatively low percentages in the Assigned Action column at least partially reflect the percent of aircraft with assigned actions to recall. Expert 1 supports the memorability of this element when he says, “I knew what I had to do with the airplane and, depending on whether there was any other traffic around, I knew basically what he was doing.” Expert 1 goes on to say that the easiest portion of recall was, “…what they were doing. It’s the job.” Thus, the recall of assigned actions is likely higher than the values in Tables 3 and 4. (A recording of the communications data would have allowed the identification of all aircraft that had recently ben assigned an action.)

As can be seen by comparing the data in Table 3 and Table 4, experts tended to recall more data tag information in the Radar condition whereas the Non-Radar condition yielded better recall of assigned action. Experts’ quotes that relate to this difference are as follows:

- “I knew pretty much all the time this guy is level, this guy is climbing, and this guy is descending” (Expert 1, Radar Condition).
- “Altitudes, I remembered the altitudes” (Expert 2, Radar Condition).
- “You get it in your mind where they are and what they are doing…” (Expert 1, Non-Radar Condition).
- “I was recalling point in space at that time and what their expected progress was” (Expert 3, Non-Radar Condition).

Observation of the recall process suggested that each recalled aircraft characteristic primed the next item for recall and thus each recalled item served as a prime or trigger for the next recalled item. This is consistent with Ericsson and Kintsch’s (1996) theory of long-term working memory, according to which the memory structure, i.e. the template or frame holding the expert’s knowledge of the airspace, is actually in long term memory, not working memory. Its contents are selectively activated and brought into working memory—perhaps one aircraft at a time or even one aircraft characteristic at a time. The researcher has no data to support this notion of priming other than the consistent order in which information types were recalled, together with observation of participant body language and patterns of pauses and verbalizations that suggested the experts were actively pulling items into working memory, one at a time, to be recalled, versus having multiple items active in working memory and sequentially reporting those items.

Static Versus Dynamic Information

Aircraft characteristics were independently categorized by three researchers into two types: static and dynamic. Characteristics were characterized as static if they never changed, such as call sign information, origin, destination, and type of aircraft. Dynamic characteristics either changed constantly or reflected the development of an aircraft's status or position. They include characteristics such as altitude, speed, hand-offs, point-outs, departures, and arrivals. As shown in Table 2 and Table 3, in both control conditions experts only recalled dynamic characteristics. Although call signs were reported in experts' recall stream, all participants reported obtaining call signs by looking at their flight strips. They also reported it to be the hardest to recall of the characteristics recalled. Expert 3 shed light on this when he stated, "You don't have to rely on memory for that. It is either A, on your strip, or B, on your strip and on the scope... so I usually don't try to retain the call sign." No other recalled data were recalled from flight strips or found elsewhere in the recall environment. Although the use of the flight strips could be viewed as compromising the results of this study, this researcher views it as informative regarding the relationships between memory contents and environmental cues.

Organization of Recall

All data were recalled on an aircraft-by-aircraft basis. That is, one hundred percent of recalled information was recalled as part of series of cohesive streams of information about specific aircraft. This quote from Expert 3 suggests the recall of an integrated set of information: “I didn’t really recreate the map, I recreated the traffic situation, the approximate location of the aircraft and, in particular, their line of flight or what their progression was going to be.” This integrated set of data suggests that memory storage structures might take the form of aircraft-centered templates organized within one large template that is structured like the airspace. This is consistent with Cohen (2000) and Gobet & Simon’s (1996) re-characterization of chunks as templates and their finding that working memory can hold 3 to 5 and 2 to 3 templates, respectively, of unlimited size.

The organization of the data is also consistent with Klein, Phillips, Rall, and Peluso’s (2006) *Data-Frame Theory of Sensemaking*. In keeping with the details of that theory, the aircraft-related information elements might be assigned to preexisting *slots* in each aircraft-centered *frame,* and each aircraft frame might be used to fill in slots in an airspace-based frame. Representations of aircraft frames and slots are shown in Figure 3 and Figure 4 for the Radar and Non-Radar conditions, respectively.

Figure 3 shows the order in which the experts tended to recall the aircraft characteristics position, call sign, then data tag information in the Radar condition. In this figure, data tag information recalled may be altitude, speed, or both. The percentages between each set of slots describe the strength of the relationship between recalled items. These percentages are shown in Figure 3 for Experts 1, 2 and 3 and they indicate the percent of aircraft recalled for which the expert also recalled aircraft position then call sign, position then call sign then either data tag information or assigned action, and position then call sign, then data tag information, then assigned action.

Figure 4 shows the orders in which the experts tended to recall the aircraft characteristics of position, call sign, then data tag information in the Non-Radar condition. The strength of these patterns are indicated, as in Figure 3, by the percentages shown by each link, representing the percent of aircraft for which the prior characteristics plus the next have been recalled in the shown order. These percentages are shown in Figure 4 for Experts 1, 2 and 3 and, as in Figure 3, they indicate the percent of aircraft recalled for which the expert also recalled aircraft position then call sign, position then call sign then either data tag information or assigned action, and position then call sign, then data tag information, then assigned action.

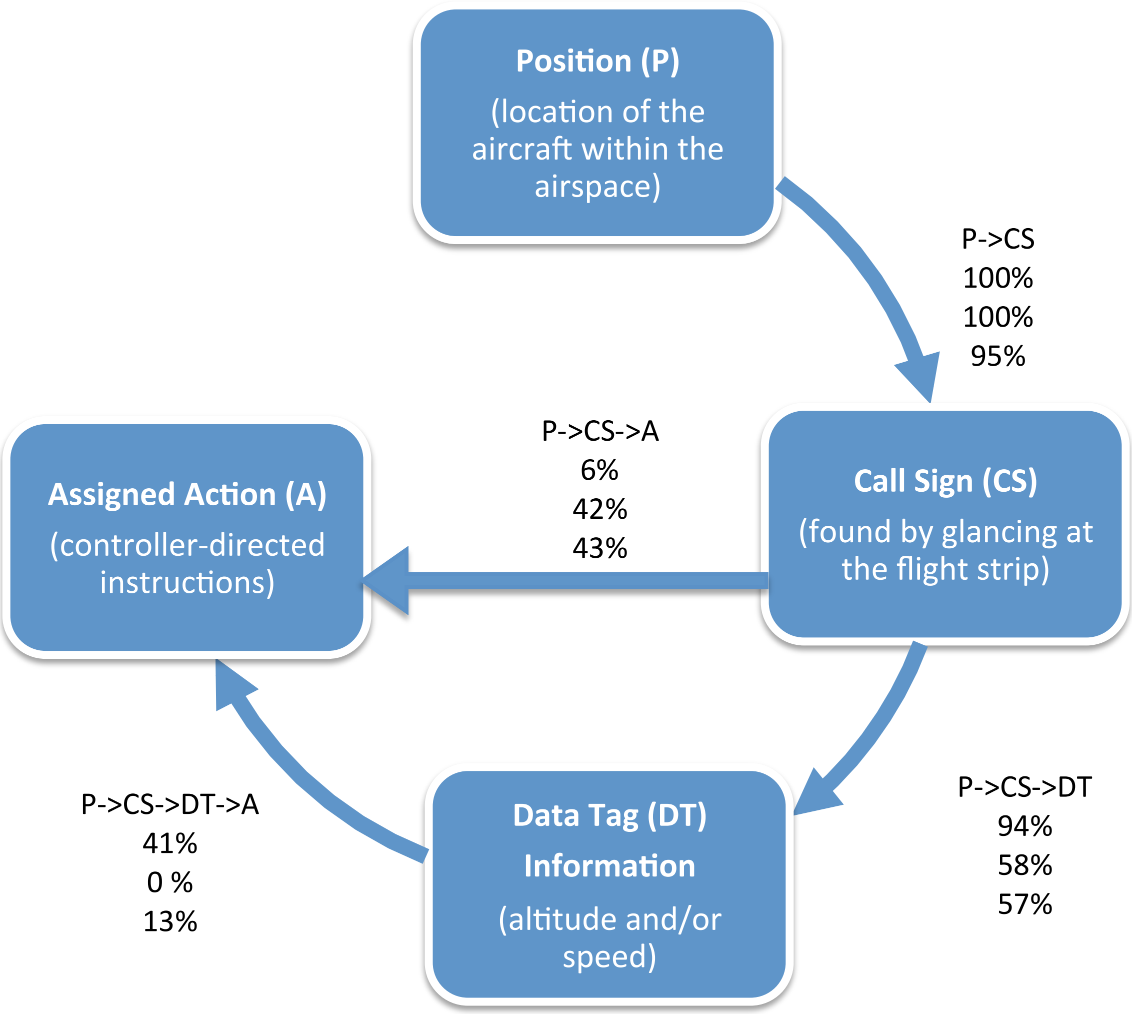


Figure 3. The Radar-condition version of the aircraft-centered template or data-frame composed of four data slots. *Note.* Each set of values indicates the percent of aircraft recalled for which Expert 1, Expert 2, and Expert 3, respectively from top to bottom of each stack of values, recalled. Moving clockwise from top, values indicate the percent of aircraft for which position then call sign were recalled; for which position, then call sign, then data tag information or assigned action were recalled; and for which position, then call sign, then data tag information, then assigned action were recalled.

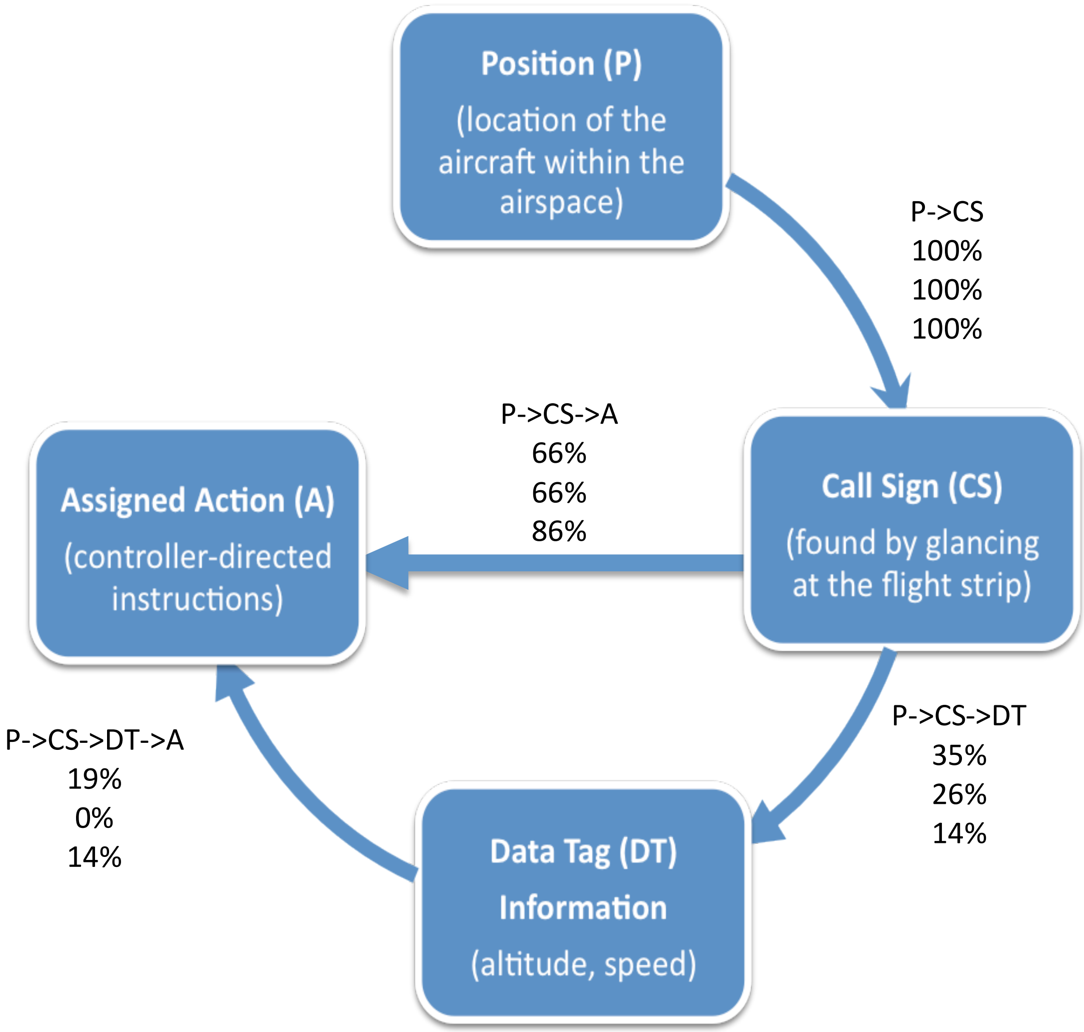


Figure 4. The Non-Radar-condition version of the aircraft-centered template or data-frame composed of four data slots. *Note.* Each set of values indicates the percent of aircraft recalled for which Expert 1, Expert 2, and Expert 3, respectively from top to bottom of each stack of values, recalled. Moving clockwise from top, values indicate the percent of aircraft for which position then call sign were recalled; for which position, then call sign, then data tag information or assigned action were recalled; and for which position, then call sign, then data tag information, then assigned action were recalled.

As seen in Figures 3 and 4, the Radar and Non-Radar conditions yielded similar aircraft characteristic recall patterns, except the order of recall for data tag information and assigned action information tended to differ. Table 5 shows, for aircraft recalled, the percent for which characteristics recall followed the two above recall patterns. The fourth item in the recall pattern for each condition was less frequently recalled; thus, the table shows the percentage of times the first three items were recalled in each order in each condition. The columns labeled with the code

P->CS->DT show the percentage of recalled aircraft for which information was recalled in the position (P), call sign (CS), and data tag (DT) succession. Columns labeled with the code *P->CS->A* show the percentage of recalled aircraft for which information was recalled in the position, call sign, and action information succession.

Table 5

The Percent of Aircraft Data Recalled in Each of the Two Common Orders

	Radar Condition P->CS->DT	Radar Condition P->CS->A	Non-Radar Condition P->CS->DT	Non-Radar Condition P->CS->A
Expert 1	94%	0%	41%	66%
Expert 2	58%	30%	26%	66%
Expert 3	57%	40%	14%	86%

Note. The code P-CS-DT represents the recall order position-call sign-data tag. The code P-CS-A represents the recall order position-call sign-action.

The above recall patterns are consistent with at least one expert's retrospective think-aloud protocol data. Expert 3 suggests recalling an entire situation as opposed to pieces of information, "…to remember the traffic situation [I usually] remember line-of-flight. I kind of put myself in the pilot's chair when I issue a clearance. As I am reading it, I am flying it." Additionally, Expert 3 adds, "…to know where the aircraft is in a point of space, altitude climbing or descending, and relative speed are what is important to me."

Modality Comparison: Recall of Visuo-Spatial vs. Verbal Information

Retrospective think-aloud data were coded to characterize responses as indicative of the use of a visuo-spatial or verbal code. Transcribed data extracts, categorized by information format code (visuospatial or verbal) are shown in Appendix M. The analysis of inter-coder reliability conducted on the pre-reconciled codes produced a Cohen's kappa coefficient of .65, which is considered a good level of agreement (Banerjee, Capozzoli, McSweeney, & Sinha, 1999). Table 6 describes the percent of data extracts in each condition to suggest each type of encoding.

Table 6

Percent of Think-Aloud Protocol Data Extracts Suggesting the Use of Verbal Versus Visuo-Spatial Encoding

	Radar Condition VisuoSpatial Format	Radar Condition Verbal Format	Non-Radar Condition VisuoSpatial Format	Non-Radar Condition Verbal Format
Expert 1	83% (10)	17% (2)	44% (4)	56% (5)
Expert 2	75% (3)	25% (1)	60% (3)	40% (2)
Expert 3	82% (9)	18% (2)	81% (13)	19% (3)

Note. Only data extracts referring to the verbal or visuospatial nature of information were extracted from the think-aloud data. Parenthesized numbers represent the total number of categorized extracts in each condition and information format.

The results of the categorization of think-aloud data extracts suggest that in the Radar condition, information tended to be encoded and processed in a visuospatial form. The picture is less clear-cut for the Non-Radar condition. Notably, the expectation that information would be encoded and processed similarly as a verbal code was not bourn out.

Conclusions

In the late 1950's and early 1960's George Briggs and Paul Fitts began studying air traffic controller recall and the effects automation has on air traffic controllers. These underpinnings have aided in studying air traffic controller memory and the interaction between air traffic controllers and the tools within their environment. Due to these early pioneers, the current study has decades of research to support the findings within.

The data patterns found in this study suggest that experts tend to recall the information that is pertinent to them to complete the task. In Gobet and Clarkson’s (2003) chess study, experts’ ability to recall recent moves as well as “attack” (action) moves were much greater than recall for other moves. This tendency for the recall of meaningful information supportive of task goals held true in the current study; the participants were able to recall aircraft information that pertained to the movement, separation, and action of aircraft within the airspace. As seen in Table 2 and Table 3, recall for these elements was very high across both control conditions.

The pattern of recall differences for static and dynamic data might be seen as related to past research of meaningful versus non-meaningful data. Chase and Simon (1973) and Gobet and Clarkson (2003) found experts’ recall of non-meaningful chess piece positions to be much lower than their recall of meaningful positions. Similarly, dynamic data in the present study tended to be recalled very well whereas static data recall was poor just as the recall of non-meaningful chess piece positions was poor.

The data patterns for the recall of aircraft and aircraft characteristics shed light on experts’ strategies, which they have adapted through years of training and experience. The recall patterns found in this study are consistent with the notion that templates are used to support the storage and retrieval of potentially large quantities of information. Templates, put simply, are conceptual structures that are used to store interrelated knowledge (e.g. Gobet & Simon, 1996). Templates can be complex structures and thus can take hours to learn. In this study, the experts’ recall seemed to suggest a traffic situation template populated by aircraft templates populated with aircraft characteristics. A study is being planned to evaluate the recall and organizational structures of student air traffic controllers.

If results are considered in terms of the Data-Frame Theory of Sensemaking, recall patterns can be viewed as suggesting slots within frames and nested frames as slots within frames. As the recall patterns suggest, each frame seemed to consist of four slots, and a range of three to seven an average of six frames (representing individual aircraft), on average, seemed to be grouped within a larger frame or template. These slots each stored information and primed the information in the next slot of the frame. The sequential triggering of elements for recall is consistent with Ericsson and Kintsch's (1995) theory of long-term working memory. It is consistent with the proposal that skilled performers rely on knowledge in long term memory and a system of retrieval cues to expand working memory capacity. When retrieval cues are triggered by relevant information in working memory, they trigger the recall of knowledge held active within long term memory; i.e., in long-term working memory.

Implications

Patterns found in this study might have implications for training strategies that could aide student air traffic controllers in school or within the FAA in building better knowledge templates and in starting to build those templates earlier. Learning material could be presented in ways that directly map to or otherwise support the development of meaningful template-based knowledge structures that may aide students in both learning and remembering greater amounts of information.

Additional implications may be found for the next generation of air traffic control technology (NextGen), which is being developed to, among other things, increase the aircraft tracking capability and capacity of air traffic controllers. This means more aircraft on a scope, more tracking, and more decision-making. One issue being considered is how much information should be displayed in the data tag to avoid display overload. The patterns found in this study suggest that very few information items are used to successfully control air traffic. Location, call sign, altitude, and speed are the primary pieces of information that participants recalled in the current study. Potentially, these are the only core pieces of information that should be included on the data tag.

The three experts in this study described using different memory and recall strategies. For example, Expert 1 says, “I think it is easier to recreate the map in the Radar, because you are constantly looking at it (on the scope). Additionally, Expert 3 describes this recall difference by saying that “In the Non-Radar (condition) I am constantly looking at key locations, separation items, and points of confliction, (but the) Radar allows you to recall the smaller pieces of information. Thus, for ERAM, creating customizable data tag displays may be beneficial.

The AT-SAT is the standardized test that all air traffic control trainees must take to be accepted to the Air Traffic Control Academy. This test consists of nine sections and takes up to eight hours to complete. One section features a recall test called *Letter Factory.* In this test, participants are asked to maintain four factory conveyer belts of varying speed. At the end of each belt is a box, which must be filled. The boxes are different colors as are the letters displayed on the conveyer belts. The purpose is to fill each box with the letters A, B, C, and D of the corresponding color. Other letters are presented on the belts, but the participant must click a quality control button off to the side of the screen when these unwanted letters are presented. Each conveyer belt has a quality control line, which indicates the point at which the letters must be placed before they are discarded and unusable. Additionally, at random times throughout the hour-long testing session, the screen will go blank and a question about the current situation will appear. Questions ask which conveyer belt had the most letters on it, which box was most full, and which belt was moving the fastest.

The results from the present study suggest that the Letter Factory test should be adapted to contain information that is meaningful to the work domain; in this case, air traffic control. Presenting scenarios such as those used in the current study and pausing each scenario to pose scenario-based questions would increase the amount of recalled data according to the results of the current study and chess studies in the past (Chase and Simon, 1973 & Gobet and Clarkson, 2003). More importantly, this change might increase the test's sensitivity to air traffic controller capability.

Follow-on research could further investigate patterns suggested by these results by studying recall in student controllers. The results of that research could be compared to the present results to refine strategies for training air traffic recall, suggest further research, and contribute to the expert-novice literature. Additionally, a study that investigates working memory capacity in experts and novices using the method of the current study but without allowing participants to use environmental artifacts, such as flight strips. Such a study would produce a purer estimate of working memory capacity than the present study. On the other hand, blocking flight strip access could disrupt the hypothesized sequential priming of templates and slots. This disruptions, in turn could cause recall patterns to disintegrate and recall to be significantly lowered.

The data patterns produced by this study suggest many implications for the future of air traffic control and potentially for our understanding of expertise and expert working memory capacity. The light that was shed on experts' memory and recall capabilities has implications for the training of novice controllers, displays for the next generation of air traffic control technology, and suggestions for the Air Traffic Selection and Training (AT-SAT) prescreening examination all air traffic controllers must complete before training. In addition, the results shed light on the knowledge organization strategies experts use and the amount of information they can actively maintain, which in-turn, contributes to the bodies of literature on working memory and long-term working memory.

References

Banerjee, M., Capozzoli, M., McSweeney, L. & Sinha, D. (1999). Beyond kappa: A review of interrater agreement measures. *Canadian Journal of Statistics, 27*, 3-23.

Baddeley, A.D., & Hitch, G.J. (1974). Working memory. In G.A. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47–90). New York: Academic Press.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology*, *4*, 55-81.

Cocchini, G., Logie, R. H., Della Sala, S., MacPherson, S. E. & Baddeley, A. D. (2002). Concurrent performance of two memory tasks: Evidence for domain-specific working memory systems. *Memory & Cognition*, *30(7)*, 1086-1095.

Cowan, N. (2000). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*, 87-185.

Ericsson, K. A. & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*, 211–245.

Gobet, F. & Clarkson, G. (2008). Chunks in expert memory: Evidence for the magical number four, or is it two? *Memory*, *12(6),* 732-747.

Gobet, F. & Simon, H. A. (1996). Templates in chess memory: A mechanism for recalling several boards. *Cognitive Psychology, 31*, 1-40.

Lehnert, G. & Zimmer, H. D. (2006). Auditory and visual spatial working memory. *Memory & Cognition*, *54*(5), 1080-1090.

Miller, G. A. (1956). The magical number seven plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *101(2),* 343-352.

Miyake, A. & Shah, P. (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. New York, NY: Cambridge Univ. Press.

Sohn, Y. W. & Doane, S. M. (2003). Roles of working memory capacity and long-term working memory skill in complex task performance. *Memory & Cognition*, *31(3),* 458-466.

Vicente, K. J. & Wang, J. H. (1998). An ecological theory of expertise effects in memory recall. *Psychological Review, 105*, 33-57.

Appendix A

Experience Questionnaire

The following questions (1-10) are a demographic and experience survey:

1. Please tell us your current age. _____
2. How many years experience do you have as an Air Traffic Controller? ______ yrs
3. How many years has it been since you retired from the FAA? ______yrs
4. If different from above, how many years has it been since you worked live traffic? ______yrs
5. What is the highest level of facility at which you worked? ____
6. For how many years did you work in a facility of that level? _____ yrs
7. With what facility types do you have experience? Please indicate the number of years of experience working in each:

   Tower only: ________ yrs
   TRACON only: ________ yrs
   Tower and TRACON:________ yrs
   ARTCC: ________ yrs

8. What is the highest position in which you worked?
   - ○ Certified Professional Controller
   - ○ Traffic Management Coordinator
   - ○ Staff Specialist
   - ○ Operational Supervisor/First-Level Supervisor
   - ○ Operational Manager/Second-Level Supervisor
   - ○ Manager/Assistant Manager
   - ○ Other (specify): ______________________

   For how many years did you work in this position? ______ yrs

9.) How many years of experience do you have instructing air traffic control students?

At Embry-Riddle? _____yrs

At FAA Academy _____yrs

Appendix B

Informed Consent Form

I voluntarily consent to participate/collaborate in the research project entitled: **Expert working memory capacity for meaningful visual and auditory stimuli.** My participation will involve controlling in four simulated traffic scenarios. I understand that I will also be asked to participate in a recall task that will involve me verbally recalling traffic information in the scenarios I will be controlling. I also understand that I will participate in a think-aloud task in which I will be asked to describe how I stored and recalled information.

The principal investigator of the study is **Mr. Joseph M. Jaworski**, a graduate student in the ERAU Human Factors and Systems Department**.** If I have questions about this study, I should inform contact Joseph Jaworski at 716-713-9397 or jaworksj@my.erau.edu. Further questions can be answered by contacting the faculty research advisor, Dr. Neville at 386-226-4922 or nevillek@erau.edu.

I understand that the investigators believe that the risks and discomforts to me are as follows:

- *No greater than would be experienced in the everyday working environment as a Radar and Non-Radar certified professional controller*

The benefits that I may expect from my participation in this study are minimal. I understand that while there are no guaranteed benefits, the results of this study can be used to learn more about expert cognitive capacities.

My confidentiality during the study will be ensured by assigning me an identification number. My name will not be directly associated with any data. The confidentiality of the information related to my participation in this research will be ensured by maintaining records only coded by identification numbers.

The individual above or a member of his research team has explained the purpose of the study, the procedures to be followed, and the expected duration of my participation. Possible benefits of the study have been described.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction. Furthermore, I understand that **I am free to withdraw consent at any time** and to discontinue participation in the study without prejudice to me.

Finally, I acknowledge that I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: ___________________________

Name *(please print)*: _______________________________
(Participant)
Signed: ____
(Participant)
Signed: ____
(Researcher/Assistant)

Appendix C

Audio and Video Data Collection Permission Form

As part of this research project, you will be audio recorded during all four traffic scenarios as well as the evaluation after the completion of the scenarios. We would like you to indicate what uses of these audio recordings you are willing to consent to by initialing below. You are free to initial any number of spaces from zero to all of the spaces, and your response will in no way affect your credit for participating. We will only use the audio recordings in ways that you agree to. In any use of these audio recordings, your name would *not* be identified. If you do not initial any of the spaces below, the audio recordings will be destroyed.

The audio recordings can be studied by the research team for use in the research project.	Please initial:
The audio recordings can be studied by members of the research team for use in future related research projects.	Please initial:
The audio recordings can be shown at meetings of scientists interested in the study of cognition and learning in complex domains.	Please initial:
The audio recordings can be shown in classrooms to students.	Please initial:
The audio recordings can be shown in public presentations to nonscientific groups.	Please initial:

FOR QUESTIONS ABOUT THE STUDY

- Questions, Concerns, or Complaints: If you have any questions, concerns or complaints about this research study, its procedures, risks and benefits, or alternative courses of treatment, you should ask the principle investigator Joseph Jaworski. You may contact ask questions now or later at 716-713-9397 or jaworksj@my.erau.edu.
- Independent of the Research Team Contact: If you are not satisfied with the manner in which this study is being conducted, or if you have any concerns, complaints, or general questions about the research or your rights as a research study subject, please contact the Embry Riddle Aeronautical University Internal Review Board (IRB) to speak to an informed individual who is independent of the research team. The ERAU IRB point of contact is Dr. Albert Boquet (386-226-7035; albert.boquet@erau.edu).

I have read the above description and give my consent for the use of the video and audio recordings as indicated above.

Date: ___________________________

Name *(please print)*: _______________________________

(Participant)

Signed: ____

(Participant)

Signed: ____________________________________

Appendix D

The Master Plan for Experimentation Day

Before experiment begins

- Check that camera sound is off
- Synch watches (if avail) with master clock
- Set up video camera over the non-dominant writing shoulder
- Make sure maps are in order of scenario
- Make sure sets of flight strips are in order
- Have extra black and red sharpies on hand
- Make sure there is a non-radar pre-planning guide at the console
- Make sure each of the following aides have their instructions:
    - *Experimenter*
    - *Assistant One*
    - *Assistant Two*
- Have a profile form at the console for the participant to fill out

Beginning of experiment

Hand out consent forms for reading over and signing – Experimenter will read the Welcome and Instructions

Once seated pseudo pilot will do an audio check with the controller.

Assistant One will be at the Master Console preparing the beginning scenario

Assistant two will have the first set of flight strips ready to be handed to participant

On cue from the Experimenter, Assistant two will give the participant his first set of flight strips and allow the participant to “stuff” his flight strip bay. Once that is complete a 12-minute preplan session will start for the Non Radar scenarios. If it is a Radar scenario or upon completion of the preplan, Assistant one will press play on the Master Console to begin the scenario. The scenario will continue per the study.

Pauses

Each pause will last for however long the participant can recall information or 3 minutes, whichever comes first

One minute before the first scheduled pause (Please see attached form with the pre-scheduled pauses), Assistant One will return to master console.

Assistant Two will retrieve the properly coded map for that Scenario, the pause, and that Participant. The Experimenter will turn the video camera on via remote 20 seconds before the scheduled pause.

At pause

Assistant Two will place the map on the console in front of the participant.
The experimenter will be in charge of maneuvering the primary video camera to track the participant's recall.
Assistant One will ensure that a screen shot/picture of the paused screen is taken from the pseudo pilot console.

After the pause is completed, Assistant two will remove the map to put it in order.
Assistant one, will press play at the command of the Experimenter.

The previous steps will be repeated for all three pauses.

At the conclusion of the scenario (except if it is after the second R and second NR), Assistant two will collect the flight strips for that scenario and put them with the corresponding three maps from that scenario. These will be clipped together. If it is after 2nd R and NR, Assistant Two will give the Participant all completed maps thus far for reference.

At the Thinkaloud Protocol

After the second Radar scenario and after the second Non Radar scenario there will be a thinkaloud response where the participant will be asked to discuss how they recalled the information from the last pause. During this time:

Assistant Two will be in charge of manning the video camera while the experimenter asks the questions.

Assistant One has no direct duties during this time

Conclusion of Experiment
At the end of the each experiment both Assistant One and Assistant Two will help the Experimenter to organize all data collection materials:

- The flash drive with the screen shots from each pause
- The maps in order of how the participant ran the scenarios
    - The maps will be in order by pause as well
- The flight strips will be clipped to the associated maps
- All materials will be placed in a binder labeled with the coded participant's number.

Appendix E

Experiment Day Instructions for Assistant 1

Thank you for your help in the execution of this study!

Your primary duty today is to assist in the starts and pauses of the scenarios. You will be seated at the Master Console. There are four scenarios and you will have list of the order in which the scenarios will be done. In addition you will have a list of each pause time for each scenario. For each scenario (4 of them) there will be two pauses and then you will pause each scenario at the 28th minute. It will be your duty to monitor the clock to pause at the correct time.

At Pause

- Approximately 1 minute before the scheduled pause you will inform the experimenter of the upcoming pause.
- After reminding the experimenter and assistant two, you will return and remain at the master console.
- At the pre-determined pause times, you will be in charge of hitting pause to freeze the scenario.
- Once you have done this, you will walk back to where the pseudo pilot is sitting to remind them to take a screenshot of the frozen screen.
- After you have reminded them to do so, return to the main console and await the Experimenters instruction to resume the scenario.

There will be two times where the participant will be giving a verbal think-aloud response. These will be after the second Radar and the second Non-Radar scenario (i.e. if the order of the scenarios is R1, R2, NR1, NR2 the think aloud will take place after the second scenario and after the fourth scenario). You have no duties during these, so please remain at the console.

At the conclusion of the experiment you will be in charge of taking the provided flash drive and putting the screenshots on the flash drive in a folder labeled with the participants given ID.

After this you are done with your duties for that experiment. Please make sure the Experimenter gets all of the items below:

- List of scenarios
- List of pauses
- Flash drive with screenshots.

Appendix F

Experiment Day Instructions for Assistant 2

Thank you for your help in the execution of this study!

There are four scenarios being run during this study. Each of the four scenarios has three times were recall is necessary; 2 pauses during the scenario and one at the end. There are two Radar scenarios and two Non Radar scenarios.

Your primary duty is to be in control of the data collection materials (i.e. sector maps) you will be working directly with the participant to ensure they have the correctly labeled map for that scenario and for that pause (i.e. if it is the second Radar scenario on the first pause it would be coded R2 P1). In addition you will be in charge of the video camera for the thinkaloud response.

At Pause

- At each pause (three of them) you will be placing the blank sector map in front of the participant.
- Immediately when you see the pause the sector map needs to be placed in front of the participant.
- After recall or after max time has passed, please remove the map and keep them in the order in which they were completed.

After each scenario

After you remove the sector map at the completion of each scenario (after the third pause) you will be in charge of giving the participant their next set of flight strips and collecting the old set of flight strips.

Thinkaloud Response

- After the second Radar scenario and after the second Non Radar scenario there will be a thinkaloud response where the participant will be asked to discuss how they recalled the information.
- During this time you will be in charge of manning the video camera while the experimenter asks the questions.

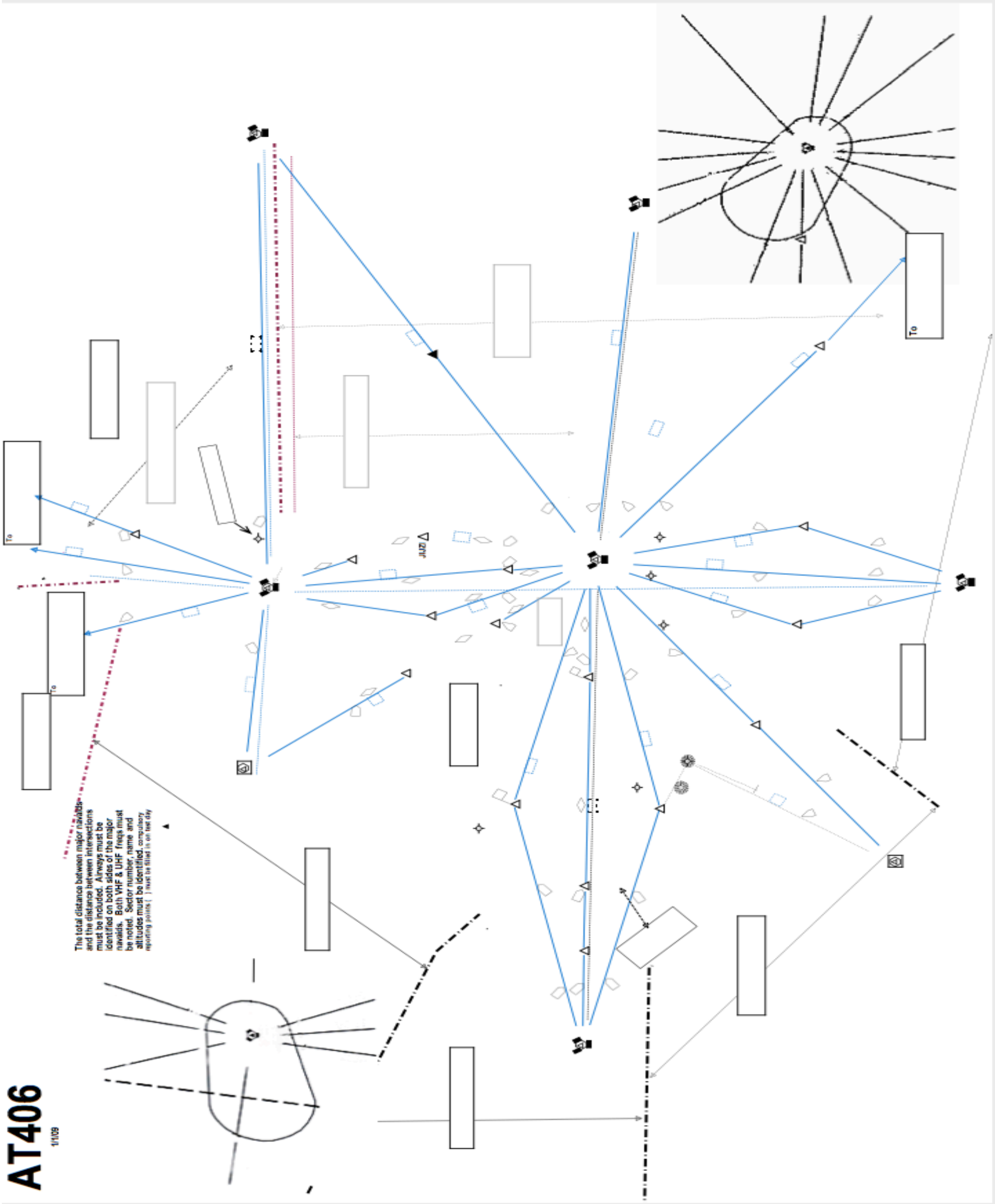
At the end of the experiment, you will be in charge of organizing the maps in order of scenario and pause.

Please make sure the following items are returned to the experimenter:

- Flight strips in order of scenario
- Maps in order of scenario and pause

Appendix G

Blank Sector Map for the Radar Condition Used as a Reference During Recall Session



The total distance between major navaids and the distance between intersections must be included. Airways must be identified on both sides of the major navaids. Both VHF & UHF freqs must be noted. Sector number, name and altitudes must be identified. compulsory reporting points ( ) must be filled in on test day

Appendix H

Participant Scenario Sequence and Randomly Assigned Recall Times

Participant ID	Sequence
1	R1, R2, NR2, NR1
2	R2, R1, NR1, NR2
3	NR1, NR2, R2, R1

Participant One

	Pause One	Pause 2	Pause 3
R1	10	18	28
R2	10	17	28
NR2	8	19	28
NR1	11	19	28

Participant Two

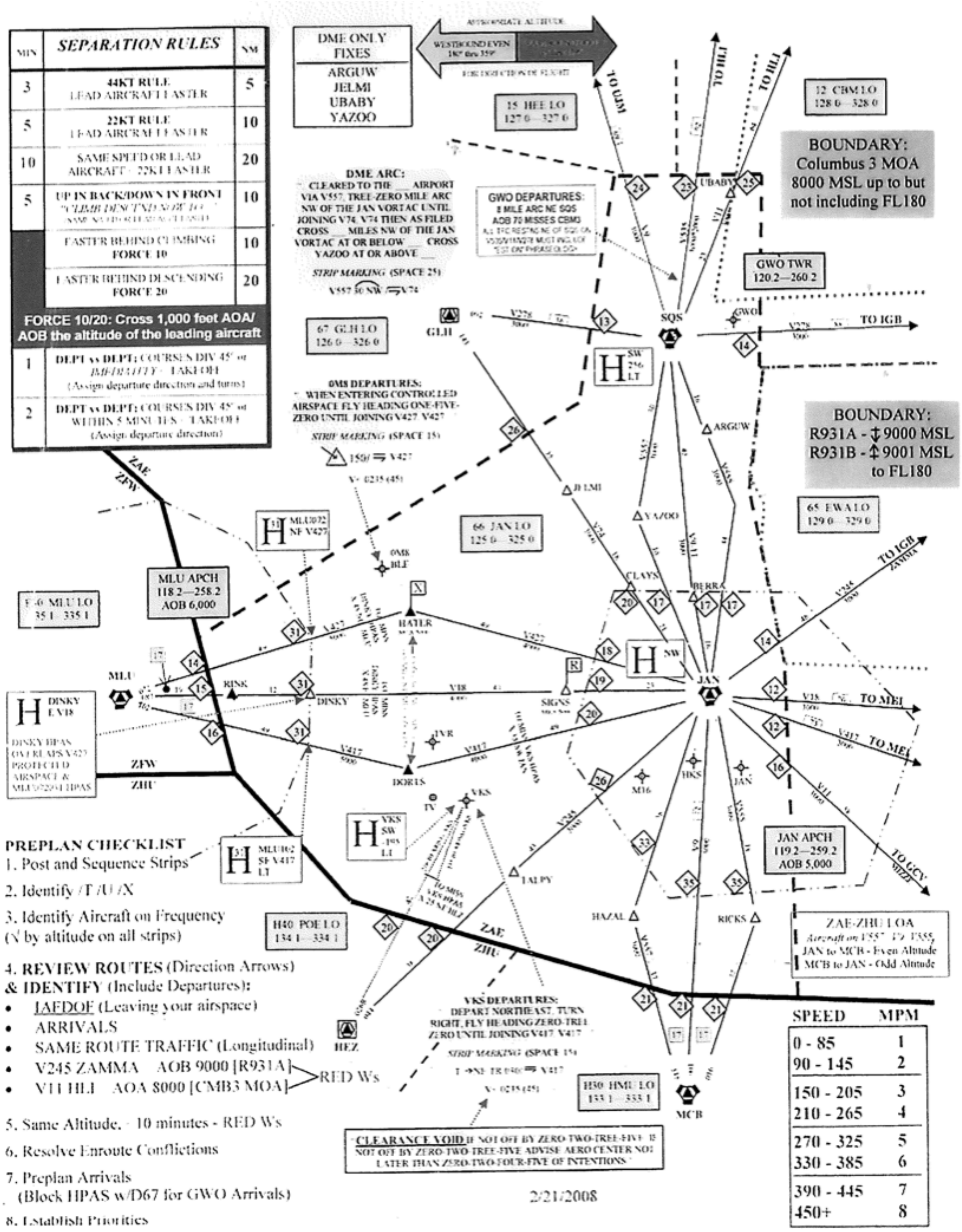
	Pause One	Pause 2	Pause 3
R2	8	18	28
R1	11	19	28
NR1	8	18	28
NR2	8	16	28

Participant Three

	Pause One	Pause 2	Pause 3
NR1	11	19	28
NR2	8	18	28
R2	10	19	28
R1	9	16	28

Appendix I

The Preplanning Guide Showing the Airspace with the Preplan Checklist



MIN	SEPARATION RULES	NM
3	44KT RULE LEAD AIRCRAFT FASTER	5
5	22KT RULE LEAD AIRCRAFT FASTER	10
10	SAME SPEED OR LEAD AIRCRAFT - 22KT FASTER	20
5	UP IN BACK/DOWN IN FRONT *"CLIMB DESCEND NOW TO"* SAME SPEED OR LEAD FASTER	10
	FASTER BEHIND CLIMBING FORCE 10	10
	FASTER BEHIND DESCENDING FORCE 20	20
FORCE 10/20: Cross 1,000 feet AOA/ AOB the altitude of the leading aircraft		
1	DEPT vs DEPT: COURSES DIV 45° or *IMMEDIATELY* - TAKEOFF (Assign departure direction and turns)	
2	DEPT vs DEPT: COURSES DIV 45° or WITHIN 5 MINUTES - TAKEOFF (Assign departure direction)	

DME ONLY FIXES
ARGUW
JELMI
UBABY
YAZOO

DME ARC:
"CLEARED TO THE ___ AIRPORT VIA V557, TREE-ZERO MILE ARC NW OF THE JAN VORTAC UNTIL JOINING V74, V74 THEN AS FILED CROSS ___ MILES NW OF THE JAN VORTAC AT OR BELOW ___ CROSS YAZOO AT OR ABOVE ___

STRIP MARKING (SPACE 25)
V557 30 NW ⇒ V74

GWO DEPARTURES:
8 MILE ARC NE SQS
AOB 70 MISSES CBM3

0M8 DEPARTURES:
" WHEN ENTERING CONTROLLED AIRSPACE FLY HEADING ONE-FIVE-ZERO UNTIL JOINING V427. V427"

STRIP MARKING (SPACE 15)
150/ ⇒ V427
V- 0235 (45)

BOUNDARY:
Columbus 3 MOA
8000 MSL up to but not including FL180

BOUNDARY:
R931A - 9000 MSL
R931B - 9001 MSL to FL180

VKS DEPARTURES:
" DEPART NORTHEAST, TURN RIGHT, FLY HEADING ZERO-TREE ZERO UNTIL JOINING V417. V417"

STRIP MARKING (SPACE 15)
T →NE TR 030 ⇒ V417
V- 0235 (45)

"**CLEARANCE VOID** IF NOT OFF BY ZERO-TWO-TREE-FIVE. IF NOT OFF BY ZERO-TWO-TREE-FIVE ADVISE AERO CENTER NOT LATER THAN ZERO-TWO-FOUR-FIVE OF INTENTIONS"

ZAE-ZHU LOA
Aircraft on V557, V9, V555,
JAN to MCB - Even Altitude
MCB to JAN - Odd Altitude

DINKY HPAS OVERLAPS V427 PROTECTED AIRSPACE & MLU072051 HPAS

PREPLAN CHECKLIST
1. Post and Sequence Strips
2. Identify /T /U /X
3. Identify Aircraft on Frequency
(√ by altitude on all strips)
4. **REVIEW ROUTES** (Direction Arrows)
& IDENTIFY (Include Departures):
- IAFDOF (Leaving your airspace)
- ARRIVALS
- SAME ROUTE TRAFFIC (Longitudinal)
- V245 ZAMMA AOB 9000 [R931A]
- V11 HLI AOA 8000 [CMB3 MOA]

RED Ws

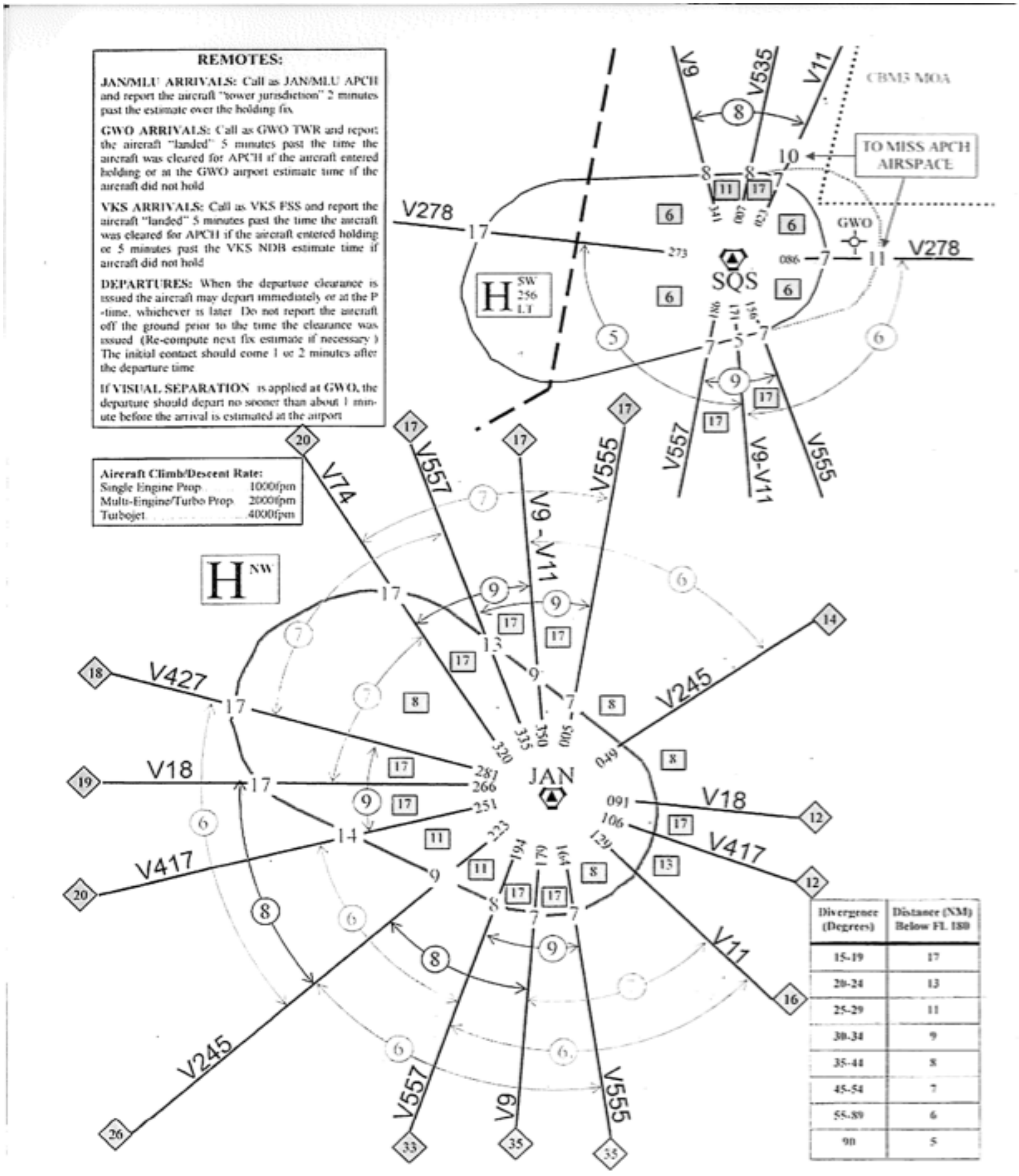
5. Same Altitude. - 10 minutes - RED Ws
6. Resolve Enroute Conflictions
7. Preplan Arrivals
(Block HPAS w/D67 for GWO Arrivals)
8. Establish Priorities

SPEED	MPM
0 - 85	1
90 - 145	2
150 - 205	3
210 - 265	4
270 - 325	5
330 - 385	6
390 - 445	7
450+	8

2/21/2008

Appendix J

The Preplanning Guide Showing the Degrees Divergence for the Holding Patterns



REMOTES:

JAN/MLU ARRIVALS: Call as JAN/MLU APCH and report the aircraft "tower jurisdiction" 2 minutes past the estimate over the holding fix.

GWO ARRIVALS: Call as GWO TWR and report the aircraft "landed" 5 minutes past the time the aircraft was cleared for APCH if the aircraft entered holding or at the GWO airport estimate time if the aircraft did not hold

VKS ARRIVALS: Call as VKS FSS and report the aircraft "landed" 5 minutes past the time the aircraft was cleared for APCH if the aircraft entered holding or 5 minutes past the VKS NDB estimate time if aircraft did not hold

DEPARTURES: When the departure clearance is issued the aircraft may depart immediately or at the P-time, whichever is later. Do not report the aircraft off the ground prior to the time the clearance was issued. (Re-compute next fix estimate if necessary.) The initial contact should come 1 or 2 minutes after the departure time

If **VISUAL SEPARATION** is applied at GWO, the departure should depart no sooner than about 1 minute before the arrival is estimated at the airport

Aircraft Climb/Descent Rate:

Single Engine Prop	1000fpm
Multi-Engine/Turbo Prop	2000fpm
Turbojet	4000fpm

Divergence (Degrees)	Distance (NM) Below FL 180
15-19	17
20-24	13
25-29	11
30-34	9
35-44	8
45-54	7
55-89	6
90	5

Appendix K

Total Number of Aircraft Recalled/Total Number Aircraft Available to Recall by Scenario and Pause for Each Participant

Participant One

	Radar 1	Radar 2	Non-Radar 2	Non-Radar 1
Pause 1	9/10	6/6	2/5	5/6
Pause 2	10/12	8/9	6/9	9/10
Pause 3	5/8	6/7	5/7	5/8

Participant Two

	Radar 2	Non-Radar 1	Radar 1	Non-Radar 2
Pause 1	6/6	5/7	7/8	2/3
Pause 2	6/7	4/5	10/11	6/7
Pause 3	5/6	4/6	5/5	6/11

Participant Three

	Non-Radar 1	Non-Radar 2	Radar 2	Radar 1
Pause 1	4/6	4/6	4/6	6/9
Pause 2	2/5	3/7	8/10	7/9
Pause 3	4/6	4/5	5/9	5/6

Appendix L

Recalled Aircraft Details by Scenario and Pause for Each Participant

Participant One

	Location	Call Sign	Altitude	Speed
R1 P1	9	9	9	3
R1 P2	10	10	10	2
R1 P3	5	5	5	0
R2 P1	6	6	6	4
R2 P2	8	8	8	3
R2 P3	6	6	6	0
NR2 P1	2	2	2	0
NR2 P2	6	6	6	0
NR2 P3	5	5	5	0
NR1 P1	5	5	5	0
NR1 P2	9	9	5	0
NR1 P3	5	5	5	0

Participant Two

	Location	Call Sign	Altitude	Speed
R2 P1	6	6	6	0
R2 P2	6	6	6	0
R2 P3	5	5	5	0
NR1 P1	5	5	4	0
NR1 P2	4	4	3	0
NR1 P3	4	4	3	0
R1 P1	7	7	7	0
R1 P2	10	10	10	0
R1 P3	5	5	5	0
NR2 P1	2	2	2	0
NR2 P2	6	6	4	0
NR2 P3	6	6	4	0

Participant Three

	Location	Call Sign	Altitude	Speed
NR1 P1	4	4	3	0
NR1 P2	2	2	2	0
NR1 P3	4	2	4	0
NR2 P1	4	3	4	0
NR2 P2	3	2	3	0
NR2 P3	4	4	4	0
R2 P1	4	4	3	1
R2 P2	8	5	8	2
R2 P3	5	4	2	0
R1 P1	6	5	6	2
R1 P2	7	7	7	1
R1 P3	5	4	5	0

Appendix M

Coded Retrospective Think-Aloud Protocol Data Extracts

Expert	Condition	Think-Aloud	Coder 1	Coder 2	Reconciled
1	R	(I recreated the map) mainly by looking at the strips	PL	N/A	PL
1	R	When the radar screen goes out that is what you refer to. That's really basically it, you look at the strips	NA	NA	NA
1	R	You see I descended this guy, or climbed this guy or had this guy on a heading or I assigned a speed to this guy	VSSP	VSSP	VSSP
1	R	All that information is over here (strips) so that you can just recreate it here (on map)	PL	PL	PL
1	R	You don't remember identification all that much.	N/A	N/A	N/A
1	R	I can remember that there is a United here. I can remember that there is a Southwest here	VSSP	VSSP	VSSP
1	R	But to say this is United 653 that part just doesn't come, you are going to get that information from either the radar scope or from the strips.	N/A	N/A	N/A
1	R	Like I said that's just the way they are remembered (Strips)	PL	N/A	N/A
1	R	I knew what I had to do with the airplane	VSSP	VSSP	VSSP
1	R	(Depending on if there) were any other traffic around, I knew basically what he was doing	VSSP	VSSP	VSSP
1	R	It's (locations) just something that you kind of just	N/A	N/A	N/A
1	R	Keep in your mind	VSSP	N/A	VSSP
1	R	For that instance when the Radar scope goes out	N/A	N/A	N/A
1	R	You, you have in your mind ... you don't know precisely where they were	VSSP	VSSP	VSSP
1	R	You know he was approximately 10 miles southeast of Viksburg or he was approximately 30 miles west of Jackson.. something like that	VSSP	VSSP	VSSP

1	R	To know precisely, not so much	N/A	N/A	N/A
1	R	There was one instance when I did not recall all of my aircraft.	N/A	N/A	N/A
1	R	There was a Muskey (points on scope) Coming across here (tracks the flight path of the Muskey on the scope)	VSSP	VSSP	VSSP
1	R	(Hardest part of recall was) basically trying to remember who was there	N/A	N/A	N/A
1	R	What they were doing wasn't so much of a challenge because I had that, I knew what was going on	VSSP	VSSP	VSSP
1	R	But its call sign, that you have trouble recalling	N/A	PL	N/A
1	R	What they were doing (was easiest item to recall)	VSSP	VSSP	VSSP
1	R	Because it's the job.	N/A	N/A	N/A
1	R	I knew pretty much all the time this guy is level, this guy is climbing, this guy is descending… you know that kind of thing.	VSSP	VSSP	VSSP
1	NR	Looking at the strips (as a strategy of recall)	PL	PL	PL
1	NR	That's all you can do. Strips tell you exactly where the airplanes are	N/A	N/A	N/A
1	NR	Location (was easiest item to recall). You kind of get it in your mind what they are doing	VSSP	VSSP	VSSP
1	NR	Radar you are constantly looking	VSSP	VSSP	VSSP
1	NR	You have a constant altitude readout	PL	PL	PL
1	NR	In non-radar you only have what they tell you	PL	PL	PL
1	NR	So you know if he has reported leaving 7,000 but he is climbing to 14,000	N/A	PL	PL
1	NR	You know he is somewhere in that (altitude) range	VSSP	VSSP	VSSP
1	NR	When you have the radar, you know, you look at it, he is you know 12,600 exactly, you know exactly where he is at. But on the radar…	N/A	N/A	N/A
1	NR	All you have is a range of altitude that he could be in somewhere.	VSSP	VSSP	VSSP

1	NR	Well, I think it is easier to recreate the map in the Radar because you are constantly looking at it. In the non-radar…	N/A	N/A	N/A
1	NR	You have to go to each strip and say ‘oh okay’ this guy just reported here at this altitude, or whatever.	PL	PL	PL
2	R	From memory (I recreated the map)	VSSP	VSSP	VSSP
2	R	Call signs were the hardest item to recall	N/A	N/A	N/A
2	R	Altitudes (were easiest to recall). I just… I remembered the altitudes. That’s all.	N/A	VSSP	VSSP
2	R	I looked at the strips for the call signs (as a strategy to recall)	PL	PL	PL
2	R	It is more difficult (to recall) the greater number of airplanes you have so it depended on when the request was made to remember.	N/A	N/A	N/A
2	R	If there are few airplanes it is easier to remember than if you had a whole bunch	VSSP	N/A	N/A
2	R	I think I got (recalled) most of them	N/A	N/A	N/A
2	R	Their relative area was pretty close	VSSP	N/A	VSSP
2	R	25 years of experience (made it easy to remember since I didn’t have my scope)	N/A	N/A	N/A
2	NR	I recreated the maps in my mind, knowing the area and knowing where everything is in that area	VSSP	VSSP	VSSP
2	NR	Remember the call signs was the hardest part to recall	N/A	N/A	N/A
2	NR	Altitude (was easiest item to recall)	PL	PL	PL
2	NR	Just the strips (was a strategy to recall). Checking the strips for call signs	PL	PL	PL
2	NR	It's harder in non-radar because I cannot see the airplanes you really have to think about it	VSSP	VSSP	VSSP
2	NR	Visual aide in Radar is what helps you recall	VSSP	VSSP	VSSP
3	NR	I didn’t really recreate the map	N/A	N/A	N/A
3	NR	I recreated the traffic situation, the approximate location of the aircraft and in particular, what their line of flight was or what their progression was going to be	VSSP	VSSP	VSSP
3	NR	To remember traffic it is usually line-of -flight	VSSP	VSSP	VSSP
3	NR	I put myself in the pilots chair, when I	VSSP	VSSP	VSSP

		read it I am flying it, so to speak			
3	NR	I remember points of confliction, I remembered how I have separated traffic on airways or vertically	PL	VSSP	PL
3	NR	What he is doing, what his altitude is (is what I could remember after knowing location)	VSSP	VSSP	VSSP
3	NR	Knowing where the aircraft is in a point of space, altitude climbing or descending, and its relative speed are what is important to me	VSSP	VSSP	VSSP
3	NR	As long as I knew they were separated, if I needed to talk to them their call sign was on the strip	VSSP	VSSP	VSSP
3	NR	I was recalling point in space at the time you asked me and what their expected progress was	VSSP	VSSP	VSSP
3	NR	Are they climbing or descending, and what their next fix was and my intent to deal with them there	VSSP	VSSP	VSSP
3	NR	My arrivals (were easiest to recall) and…	N/A	N/A	N/A
3	NR	How they stacked up in the holding pattern	VSSP	VSSP	VSSP
3	NR	Whether they were cleared for an approach or if they were still inbound	PL	VSSP	PL
3	NR	So I remembered my arrivals first because they impact you the most because…	N/A	N/A	N/A
3	NR	You have a lot of airspace to separate	VSSP	VSSP	VSSP
3	NR	(Then I remember) anything that's pending, nagging at me (a departure I haven't released yet or whatever)	PL	N/A	PL
3	NR	Call signs were hardest to recall	PL	N/A	N/A
3	NR	(When asked why call signs were hardest to recall) Because you don't have to rely on memory for that. It is either A of your strip or A and B on your strip and on the scope. But here it is on the Radar, when you need to talk to them it's like looking a person in the eye…	PL	N/A	N/A
3	NR	You look at the flight strip and the call sign is right there, so I usually don't retain them	PL	PL	PL

3	NR	The ones you work every day you remember, but others they change every day.	N/A	N/A	N/A
3	NR	I know where the aircraft is in that particular time, I know about where it should be	VSSP	VSSP	VSSP
		That’s why sometimes I double-check or…	N/A	N/A	N/A
3	NR	Get a progress report to make sure I have fresh information in my head about where he is	PL	VSSP	PL
3	NR	I carried most of it except for call signs and some type aircraft	VSSP	N/A	VSSP
3	R	Recreating the map in the Radar condition was a lot easier.	N/A	N/A	N/A
3	R	In radar you are constantly staring at them	VSSP	VSSP	VSSP
3	R	You get constant updates	PL	PL	PL
3	R	So pinpointing aircraft is a lot easier, and I don’t have to carry it in my dead that much and keep visualizing it as much	N/A	N/A	N/A
3	R	I just refresh every time I talk to an airplane	PL	VSSP	VSSP
3	R	I am looking at the next one, and if I talk to that one I am looking at the next one. My eyes are always one step ahead of what I am looking at and doing at the time	VSSP	VSSP	VSSP
3	R	Carrying a long-term movement of an aircraft isn’t necessary	VSSP	N/A	N/A
3	R	(It usually comes the) first time I talk to an aircraft I store information: who, what, where, and where he is going	PL	VSSP	VSSP
3	R	I make an effort the first time I talk to an aircraft or the first time I identify or accept communication transfer or whatever it happens to be, to…	N/A	N/A	N/A
3	R	Kind of store in place who he is, where he is going, and everything else kind of falls into place like that, because speed is on the scope, his call sign is on the scope.	N/A	VSSP	VSSP
	R	Nothing was harder to recall but it was a little harder to… as the airspace next to, down from, or up north from you…	N/A	N/A	N/A

3	R	You make a mental note to make sure you don’t lose track of your airspace, but as	PL	N/A	PL
3	R	You get busy with other calls in that narrow neck of the airspace guys get awful close to being late as far as handoffs and communication transfers.	PL	N/A	N/A
3	R	Everything was easier in the Radar condition. Everything except phraseology. Phraseology is consistent, it’s the dame and coordination is easier in Radar than it is in non-radar because you can look at it and see if you have time to wait or is it time to do it now. In non0radar you have to do it when the opportunity presents itself. In Radar you can do it in a more timely fashion, you can wait until the aircraft is just about at the boundary.	N/A	N/A	N/A
3	R	In non-radar you have to do it at a fix they report because you have no visual indicators	PL	PL	PL
3	R	(Non-Radar is easier to recall because) you are constantly storing and updating that information.	VSSP	VSSP	VSSP
3	R	In radar it is there in front of you and it takes less time and conscious effort to update a traffic pattern if…	N/A	N/A	N/A
3	R	You are taking snapshots of it (Radar scope) six times a minute	VSSP	VSSP	VSSP
3	R	In non-radar the moment an aircraft enters your airspace you have to keep a mental track of where he is.	VSSP	VSSP	VSSP
3	R	(When asked which condition they recalled more in) Radar.	N/A	N/A	N/A
3	R	In non-radar I’m looking at key locations, separation items, and points of confliction	VSSP	VSSP	VSSP
3	R	Radar allows you to recall the smaller pieces of information	VSSP	N/A	N/A