INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

**ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600**

UMI[®]

**The Effects of Operator Interface on Head Position, and Workload:
Direct Voice Input versus Manual Input for the CH-146 Griffon Helicopter**

Lynda Lessard

**Thesis presented to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of**

Master of Arts

Department of Psychology

Carleton University

Ottawa, Canada

**National Library
of Canada**

**Acquisitions and
Bibliographic Services**

**395 Wellington Street
Ottawa ON K1A 0N4
Canada**

**Bibliothèque nationale
du Canada**

**Acquisitions et
services bibliographiques**

**395, rue Wellington
Ottawa ON K1A 0N4
Canada**

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-60994-4

Canada

The undersigned recommend to the
Faculty of Graduate Studies and Research
Acceptance of the thesis:

"The Effect of Operator Interface on Head Position, and Workload:
Direct Voice Input versus Manual Input for the CH-146 Griffon Helicopter"

submitted by

Lynda Lessard

in Partial fulfillment of the requirements for
the degree of Master of Arts

Chair

Thesis Supervisor

Carleton University
May, 2001

Abstract

The present study reports on the impact of implementing a Direct Voice Input (DVI) system on head position and workload in the CH-146 Griffon helicopter. Twelve Canadian Forces Griffon helicopter pilots, in crews of 2, performed reconnaissance missions in a moderate-fidelity flight simulator. Experiment 1 examined the relative effects of DVI versus a standard manual input system on head position for flying pilots (FPs) and non-flying pilots (NFPs). Experiment 2 examined the relative effects of DVI and manual input on mental workload using a secondary visual and auditory target detection task. Using DVI, NFPs looked up more, looked at control display units, and map/instruments less, and experienced a reduction in workload compared to manual input. FPs showed no change in head position, and experienced increased workload using DVI compared to manual input. These results suggest a benefit for NFPs for head position, and a redistribution of workload for the crew.

Acknowledgement

The author gratefully acknowledges the following people for their invaluable assistance:

My advisor Dr. Chris Herdman for his expert guidance, patience, and much appreciated editorial assistance.

Members of the HFE group at CMC Electronics for their continued technical support throughout this project.

My committee members for their participation and constructive feedback.

My family and friends for their continued support and understanding. In particular, Christy Chesley for her editorial assistance.

Cameron Hunter for his interest, patience, and ongoing support.

Table of Contents

List of Tables	vii
List of Figures	viii
List of Appendices	x
Introduction	1
CH-146 Griffon Helicopter	4
Prototype DVI System for the CH-146 Griffon	6
Testing Facility	6
Flight Model	8
DVI Software Distribution	8
Communications System Console Panel	9
Feedback System	9
Syntax	11
Introduction to the Current Study	12
Experiment 1 - Introduction	12
Methods	16
Participants	16
Controlling Agencies	17
Schedule of Experimental Trials	18
Procedure	20
Missions	21
Results and Discussion	22
Head Position	23
Percent Head-Up Time	23
Percent CDU Time	26
Percent Map/Instruments Time	28
Subjective Workload Results	30
Summary of Experiment 1 Results	33
Experiment 2 - Introduction	35
Methods	42
Participants	42
Materials and Procedure	42
Results and Discussion	44
Head Position	44
Percent Head-Up Time	44
Percent CDU Time	46
Percent Map/Instruments Time	48
Summary of Head Position Results	50
Latency Results	51
Summary of Latency Results	54
Overall Mean Percent Correct Responses	54
Mean Percent Correct Responses by Head Position	56
Mean Percent Correct Responses while Looking Up	56

	Mean Percent Responses while Looking at CDUs	58
	Mean Percent Correct Responses Looking at Map	60
	Summary of Mean Percent Correct Responses	61
General Discussion		62
	Head Position	62
	Workload	64
	Conclusion	67
References		68
Appendix A		70
Appendix B		82
Appendix C		83
Appendix D		85
Appendix E		86
Appendix F		87
Appendix G		88
Appendix H		91
Appendix I		93
Appendix J		101

List of Tables

1. Participant demographics	16
2. Schedule of experimental trials	18
3. Experiment 1 – Summary of head position findings	34
4. Experiment 2 – Summary of head position findings	51

List of Figures

1. Photo of the CH-146 griffon helicopter	4
2. Physical layout of the simulator	6
3. Control display unit (CDU) used for trials	7
4. Explanation of DVI feedback display	10
5. a) Heading – top view	13
b) Pitch – side view	14
c) Roll – rear view	14
6. Mean percent head-up time by role, input type and mission segment (CRM uncontrolled)	25
7. Mean percent head-up time by role, input type and mission segment (CRM controlled)	25
8. Mean percent CDU time by role, input type and mission segment (CRM uncontrolled)	27
9. Mean percent CDU time by role, input type and mission segment (CRM controlled)	27
10. Mean percent map/instruments time by role, input type and mission segment (CRM uncontrolled)	29
11. Mean percent map/instruments time by role, input type and mission segment (CRM controlled)	30
12. FPs' mean workload ratings by workload type and input type	32
13. NFP's mean workload ratings by workload type and input type	32
14. Mean percent head-up time by role, input type, and mission segment (CRM uncontrolled)	45
15. Mean percent head-up time by role, input type, and mission segment (CRM controlled)	46
16. Mean percent CDU time by role, input type and segment (CRM uncontrolled)	47
17. Mean percent CDU time by role, input type, and mission segment (CRM controlled)	48
18. Mean percent map/instruments time by role, input type, and segment (CRM uncontrolled).	49
19. Mean percent map/instruments time by role, input type, and mission segment (CRM controlled)	50
20. Mean latency difference by role, input type and target type (CRM uncontrolled)	53
21. Mean latency difference by role, input type and target type (CRM controlled)	53
22. Mean percent correct response difference by role, input type, and target type (CRM uncontrolled)	55
23. Mean percent correct response difference by role, input type, and target type (CRM controlled)	55

24. Mean percent correct responses while head-up by role, input type, and target type (CRM uncontrolled)	57
25. Mean percent correct responses while head-up by role, input type and target type (CRM controlled)	58
26. Mean percent correct responses for NFPs while looking at CDUs by input type, and target type (CRM uncontrolled)	59
27. Mean percent correct responses for NFPs while looking at CDUs by input type, and target type (CRM controlled)	59
28. Mean percent correct responses for NFPs while looking at map/instruments by input type, and target type (CRM uncontrolled)	60
29. Mean percent correct responses for NFPs while looking at map/instruments by input type, and target type (CRM controlled)	61

List of Appendices

A. Information Mail-out Sent to Participants	70
B. Background Information Form	82
C. Informed Consent Form	83
D. Debriefing Form	85
E. Mission Scenario	86
F. Map Using the Military Grid Reference System	87
G. Workload Questionnaire	88
H. Description of Mission Segments	91
I. ANOVA Tables and Tables of Means and Standard Deviations – Experiment 1	93
J. ANOVA Tables and Tables of Means and Standard Deviations – Experiment 2	101

The Effects of Operator Interface on Head Position and Workload:

Direct Voice Input versus Manual Input for the CH-146 Griffon Helicopter

As new avionics systems have become available, aircraft cockpits have become increasingly more complex. This in turn, has placed greater demands on pilots, who have been forced to perform progressively more difficult tasks in progressively more dangerous and demanding environments. Until recently, engineers were solely responsible for ensuring new avionics components functioned effectively. However, their focus was on the development of technology solutions, rather than on the design of advanced systems from the perspective of the human as an information processor. With conservative estimates attributing 65% of all aviation accidents worldwide to human error (Hart, 1988) a new awareness of the importance of human factors research has emerged, focusing on examining the adequacy of the interface between pilots and the systems they interact with. Therefore, for flight safety reasons, the most efficient use of pilot resources must be determined through testing of new systems and interfaces in order to design the most effective cockpit. The current study was designed to examine the effects of one technology that may be beneficial to aircraft cockpits, specifically, direct voice input (DVI).

DVI was proposed as an interface to aircraft displays many years ago (Coler, 1982; Walters, 1985, as cited in Hart, 1988), and involves allowing pilots to communicate with their avionics management systems via voice recognition software. The primary impetus for developing a DVI system came from the need for pilots of single-piloted aircrafts to perform many tasks simultaneously. DVI was suggested because it allows pilots to operate their avionics systems by voice, without having to

remove their hands from their flight controls or disturbing their head-up and eyes-out posture. Consequently, DVI has been implemented in fixed wing aircrafts such as the single-piloted EuroFighter 2000 (Anderson, 1998). Implementation of DVI into rotary wing aircrafts has not progressed as quickly.

For many years, the main obstacle for implementing DVI in helicopters has been the high noise and vibration levels present in rotary wing aircrafts. This harsh environment causes voice recognition problems, which in turn cause pilots to become frustrated due to misrecognitions. For this reason, most of the research done to date has focused on whether or not high levels of recognition could be achieved during operational flights. Dennison (1987), for example, examined the effect of simulated helicopter vibration on voice recognition system performance. Specifically, Dennison looked at whether vibration-induced changes in voice cause difficulty for recognition systems. Twelve individuals, seated in a Bell Cobra helicopter seat mounted on an 8,000-pound capacity vibration platform, were vibrated at three intensity levels. They were required to speak a list of 50 words with and without vibration. The results showed no significant degradation of system performance for the three intensity levels. Dennison concluded that vibration should not significantly affect the use of voice recognition in helicopters.

Similarly, Junqua (1996) examined factors influencing voice changes in high noise environments. Junqua reviewed experimental results regarding the acoustic changes between normal and Lombard speech. Lombard speech occurs during high noise levels, and causes individuals to change their voice pattern (increase in frequency, level, vowel duration etc.). This in turn causes pattern recognition difficulties for speech

recognition software (i.e. the template created in a low-noise level environment doesn't match the pattern of input in the high noise level environment). Junqua concluded that Lombard speech is highly speaker-dependent and varies with gender, language, and type of noise. Junqua then recommended the use of relational features as a way to reduce the influence of the Lombard reflex on automatic speech recognizers. This study provides an example of the type of research conducted, which has led to the technological advances with voice recognition software. In addition to research conducted in simulators, recognition accuracy has also been examined in real flight situations.

Swail and Kobierski (1997) examined in-flight recognition rates using DVI in a Bell 412 helicopter. Four phases of test flight were performed: free-play (to familiarize the operator with the system); verbal rally (following ground staff through a series of frequency changes); aiding a second aircraft simulating an in-flight emergency; and normal flight (using the DVI as if it were a regular aircraft system). The test flights were conducted as though the evaluation pilot was the sole crewmember. The second pilot acted as a "safety", monitoring airspace and radio frequencies during the flight. Six pilots (1 National Research Council, 5 Canadian Forces Griffon) completed the flight trials. The results showed that recognition rates ranged from 87.4 to 99.2%. In addition, all pilots indicated that DVI could assist them in completing high workload tasks (e.g., changing radio frequencies while in a hover). These data provide support for the contention that DVI technology has advanced to the point that its use in rotary wing aircraft is possible.

CH-146 Griffon Helicopter

Now that technological concerns have diminished, DVI is being considered as an interface alternative for the Canadian Forces CH-146 Griffon helicopter. The Griffon (see Figure 1) is a multi-purpose helicopter, used for the tactical airlift of troops and equipment, aero medical support, reconnaissance and surveillance, and search and rescue. It is essentially a Civilian Bell 412, with additions such as missile warning receivers and tactical radios that make it an operational military aircraft. The flight versatility possessed by helicopters such as the Griffon creates a very challenging environment. Specifically, helicopters can move in any direction, they can hover, climb and descend vertically as well as take off and land almost anywhere. Moreover, they often fly at low altitudes in very close proximity to terrain features such as buildings and trees. Their operational environment extends from flat terrain under clear day conditions, to hazardous terrain under night operations while in unfavorable weather.

Figure 1. Photo of the CH-146 Griffon Helicopter.

The Griffon is comprised of three crewmembers: a flying pilot (FP), non-flying pilot (NFP), and flight engineer. The complexities of the operational environment and the sheer volume of information that must be processed mandate highly coordinated team performance. Therefore clearly defined standard operating procedures exist for each role within the crew. Although somewhat of an oversimplification, the current Crew Resource Management (CRM) model dictates that flying pilots must keep their hands on the cyclic and collective at all times in order to maintain control of their aircraft during flight, and must maintain a head-up, eyes-out posture. Therefore, due to these limitations, the FPs are almost exclusively limited to flying the aircraft. Conversely, the NFPs are in charge of navigation, and must therefore interpret maps, conduct terrain analyses, in addition to having to change radio frequencies, carry out all communications, select display alternatives, and input data into the Control Display Units (CDUs).

The extensive demands placed upon NFPs cause them at times to become overburdened. The problem of overtaxed NFPs is exacerbated by the interface to the CDUs. The CDUs are located low down and far back on the console separating the two pilots, and require visual attention to be focused very low in the cockpit. In fact, the CDUs have been nicknamed “head-magnets” because frequent interactions are required to gain the appropriate information for each task causing visual attention to be drawn and maintained on the CDU for long periods of time. During flight, the NFP must often hunt for information through a complex menu architecture, and at times both CDUs are required simultaneously to display pertinent information. This in turn increases workload, delays the acquisition of crucial flight information, increases head-down time, and thereby creates flight safety concerns.

Prototype DVI System for the CH-146 Griffon

A prototype DVI system for the CH-146 Griffon helicopter was developed by CMC Electronics, the Defence and Civil Institute of Environmental Medicine (DCIEM), and the Center for Applied Cognitive Research (CACR) at Carleton University. A description of the experimental set-up of the prototype DVI system follows.

Testing Facility. The DVI system was incorporated into a flight simulator facility at the Human Factors Engineering Laboratory, at CMC Electronics (Kanata, Canada). The simulator was driven by a Silicon Graphics-base workstation local area network containing 2 SGI Octanes, 2 SGI Solid Impact, and 1 SGI ONYX2 computers. The simulator's DVI physical layout is illustrated in Figure 2. It includes a flight deck structure with cockpit housing, seating for the FP (always on the right), NFP (always on the left), and experimental observer (back left), as well as low fidelity flight control systems (cyclic, collective, rudder pedals). Two portable Verbex speech recognizers were positioned behind the instrument panel.

Figure 2. Physical Layout of the Simulator.

A simulated environment was displayed on a 60-degree field of view rear projection screen positioned approximately 8 feet 7" from the viewer. Monitors displayed the simulated left, right and center instrument panels as well as the two CDUs. To enhance realism, the pilots interfaced with the CDUs using touch-activated bezels formatted to look and interact as those currently used in the Griffon Helicopter (see Figure 3). CDUs provide the interface to the Griffon's avionics management system, allowing the crew to manipulate and monitor systems such as navigation and communications. The CDUs were capable of receiving and acting upon command messages from the DVI system.

Figure 3. Control Display Unit (CDU) used for the trials.

In order to allow communication between crew and controlling agencies, headsets and microphones were worn which allowed all interactions to be heard by both pilots, and controlling agencies (airborne command and control center, and squadron command) except in private mode. Each pilot was equipped with a private mode switch (a foot pedal for the NFP and a button on the collective for the FP) which when pushed, prevented the other pilot and agencies from hearing the communication. All auditory feedback (tones), radio traffic and intercom chatter was presented over the headsets. Pilots controlled their own headset volume. Ambient aircraft noise was presented over two small speakers (< 60 dBA) positioned at the rear of the simulator. Head trackers were affixed on top of the pilots' headsets in order to measure head position throughout the trials.

Flight Model. The flight dynamics of the simulator were modeled using HELISIM, a high fidelity, 6 degrees of freedom simulation environment. The flight model utilized in the experiment was based on performance data for a Bell 412 helicopter. In addition, the flight model of the simulator was subjectively tuned to ensure a more realistic approximation of the handling characteristics of the Bell 412. A stability Augmentation System algorithm was active in the flight dynamics model for the duration of the experiment.

DVI Software Distribution. The DVI experimental prototype is composed of a number of Silicon Graphics workstations running the IRIX operating system. The simulator core software components and the DVI software elements were distributed across multiple platforms in order to take advantage of distributed processing and to optimize overall system performance.

Communications System Console Panel. The traditional CH-146 Griffon's communications system console is mechanically driven by rotary dials, therefore, the communications system console panel could not be interfaced with DVI using software. As a result, members of the human factors engineering laboratory at CMC Electronics developed a new DVI friendly communications system console panel that was created using a touch-screen overlaid on top of a liquid crystal display.

Feedback System. Both auditory and visual feedback was provided by the DVI system. Visual feedback was presented to both pilots on two, four-line by twenty-five character liquid crystal displays. The liquid crystal displays were positioned approximately 70 cm (10° visual angle) directly in front of each pilot just below the glare shield. It is believed that, similar to a head-up display, the feedback display will decrease the head movement required to gain relevant information compared to the head movement required to look at the CDUs. As illustrated in Figure 4, the top line of the feedback box displayed the current command, the second line the previous command, the third line a query or error message when necessary, and the fourth line the status of radios 1, 2, 3, and 5. A detailed explanation of the radio status symbols is described in Figure 4. In addition to the command lines, two small green lights were positioned on the top portion of the feedback display. The first light indicated whether the system was in listening (lit) or in standby mode (not lit), and the second light flashed when the system was prompting for information (such as during a calculation command, such as 'calculate endurance and range').

Figure 4. Explanation of the DVI feedback display

The auditory feedback accompanying the visual display was heard through the headsets and included four different alerting tones as follows:

1. The Querying Tone – heard when the system was put into listening mode by saying “computer” or during a calculate command when the user was being queried for information
2. The Success Tone – heard when a command was recognized and completed successfully
3. The Error Tone – heard when a command was recognized but there was an error executing the command
4. The Standby Tone – heard after uttering “Standby” and the system went into standby mode

If the system did not receive a successful command for a period of 30 seconds, it would automatically time-out, and go into standby mode. The system would then have to

be awakened by saying the word “computer”. If the system did not recognize an utterance as a valid command, no feedback would occur, as the system would be unable to differentiate the utterance from other communications within the cockpit.

Syntax. In order to identify the initial grouping of functions appropriate for control by DVI, a team from the human factors engineering lab visited an operational Griffon unit to observe crews during tactical missions. Videotaped footage of the tactical missions was then transcribed into various composite mission scenarios. These along with input from a domain expert were used to determine the master list of all functions normally implemented using the CDUs. Two rationales for inclusion were used to determine which of these commands were suitable for DVI. Commands were included if their frequency of use and their potential to lower workload were judged to be high. In other words, only commands that were currently used a lot were included, as well as commands that were relatively easy to execute with DVI compared to the manual system. The reason for these criteria was that pilots would find it difficult to use DVI if the syntax set was too large, and would choose not use DVI if they could implement the command more easily with the manual system. In addition, two rationales for exclusion were used. Commands were excluded if they were judged to be too complex or if they were judged to have a high probability of creating audio conflicts. In other words, commands were excluded if they would require a very lengthy interaction with the system. Natural and intuitive vocabulary was selected based on operational terminology observed at the Griffon site visit, as well as from input from the domain expert. The structure of the syntax took a simple and rigid form of <Action> <Target> <Parameter>. For example, one of the commands implemented was “Set <action> Radio 1 <target> 118.1

<parameter>”. This ordering of ‘action’ followed by the ‘target’ is consistent with the results of Dixon (1982), which showed that complex instructions are more quickly and accurately followed when the action word precedes the target word. The complete set of vocabulary items is listed in Appendix A.

Current Study

The goal of the current research was to compare the existing manually controlled Griffon cockpit configuration versus a DVI equipped cockpit configuration within a multi-crew environment. Two experiments were conducted. Experiment 1 established a new objective measure in order to determine the impact of DVI versus manual input on head position, and measured workload subjectively through the use of a workload questionnaire. Experiment 2 examined the impact of DVI versus manual input on workload objectively with a secondary target detection task.

Experiment 1

Research to date on DVI, other than recognition accuracy, has relied primarily on subjective measures such as workload questionnaires or general acceptance questionnaires administered during technology demonstrations. Although some insight can be gained from these measures, the need for an objective dependent measure in this area was evident. Objective measures provide a means of obtaining a non-biased evaluation of performance that is independent of participant’s beliefs.

In the current study a new objective measure, head position, was created to evaluate the impact of DVI versus manual input. DVI may potentially affect head position for the crew, particularly the NFP, by allowing pilots to input information into the CDUs while maintaining a head-up and eyes-out posture. An increase in head-up

time is widely believed to increase flight safety, as it allows the crew to maintain a high level of awareness of their position in space, as well as improving the detection of obstacles in the aircraft's path such as power lines or trees etc. Furthermore, increasing head-up time has the potential to increase mission effectiveness by allowing crews to maintain their gaze on the outside world, when necessary, such as during search and rescue or reconnaissance missions. It is predicted that DVI will increase head-up time for NFPs by allowing them to input data into the CDUs while maintaining a head-up and eyes-out posture. In contrast, it is predicted that FPs will show no change in head-up time with DVI compared to manual input, as FPs are required to maintain a head-up and eyes-out posture at all times regardless of input type. Consequently, the time spent looking at the CDUs is predicted to decrease for NFPs and remain unchanged for FPs. In terms of time spent looking at maps/instruments, it is predicted to remain unchanged for both NFPs and FPs, as the DVI system does not interact with these devices and therefore should not change the amount of head-down interaction required with them. To measure head position, head trackers attached to the pilots' headsets measured degrees of heading (see Figure 5a), pitch (see Figure 5b) and roll (see Figure 5c).

Figure 5a. Heading – Top View

Figure 5b. Pitch – Side View

Figure 5c. Roll – Rear View

Two calibration settings (looking at CDUs and looking straight ahead at the outside scene) measured in degree-x (heading) and degree-y (pitch) were used to define head-up, map/instruments, and CDU regions for each participant, on a trial-by-trial basis. Roll was not used, as it was deemed irrelevant to distinguishing head position in terms of where the participants were looking. The head-up region was defined as the area above the midpoint between the two calibration settings for degree-y (pitch). Map/instruments, and CDU regions were defined as the two areas below the midpoint for degree-y (pitch), on either side of the midpoint between the two calibration settings for degree-x (heading). The directions of the CDU and map/instruments areas reverse depending on the seating of the pilots. FPs seated on the right looked to the left to gaze at the CDUs and straight ahead to gaze at their instruments, whereas NFPs seated on the left looked to the right to gaze at the CDUs and straight ahead to gaze at their map/instruments. Head position has not been used as a dependent measure to date in this area of research, and should provide some insight into the effects of implementing a DVI system.

In addition to possibly impacting head position, DVI may have the potential to redistribute workload within the cockpit. Currently, FPs are limited to solely flying the aircraft because they must maintain an eyes-out and hands on cyclic and collective posture at all times. The standard operating procedures dictate that FPs must ask the NFPs to perform any CDU operations. Consequently, the NFPs' workload levels often exceed human performance limits as they are responsible for all tasks other than flying. With DVI FPs now have the ability to perform some tasks hands-free, while still maintaining a head-up and eyes-out posture. In order to assess the full potential of the DVI system a modified CRM was used for all DVI trials. The modified CRM consisted

of having FPs change the heading needle to the next waypoint, as well as maintaining communications with one radio agency (squadron command). Head position was measured as crews performed simulated reconnaissance missions similar to those typically performed by tactical crews in the CH-146 Griffon in order to promote a sense of realism.

Method

Participants

Eleven male and one female Canadian Forces helicopter pilot, comprising six crews, volunteered for this study. All were considered on active duty. Two pilots were recruited from each of Squadrons 438 and 430, and four were recruited from each of Squadrons 400 and 427. Ten were right-handed and 2 were left-handed. Their demographics are detailed in Table 1.

Table 1

Participant Demographics

Demographic	Mean	Range
Age	34.9	25 – 52
Years in Canadian Forces	13.9	8 – 28
Total Flight Hours	2422.2	696 – 6700
Total Griffon Hours	525.8	120 – 1100

Three of the twelve pilots had some experience with speech recognition systems. P(3) participated in the 1995-1996 voice recognition template trials at CMC Electronics (formerly Canadian Marconi Company), and P(4, 11) participated in the 1998 DVI trials at the Defence and Civil Institute of Environmental Medicine (DCIEM).

Overview

Controlling Agencies. In order to insure realism, two Carleton University Graduate students were trained to act as controlling agencies. Two additional people were trained as back-ups (the experimenter and a member of the human factors engineering lab). The training lasted approximately 4 hours, and included memorizing common aviation words and phrases and usual flight protocols, followed by an hour of role-playing with the domain expert.

The individual with the call sign Zero played the role of squadron command. The crew was instructed to engage in all communications normally executed to squadron command on similar missions, and therefore to request take-off and landing clearance, and provide Zero with status reports. The individual playing Zero was also responsible for recording the timing of events (take-off, contact visual, etc.).

The individual with the call sign Magic played the role of the Airborne Command and Control Center, and was responsible for the current mission. The crew was therefore instructed to provide Magic with continuous status reports, and contact reports when necessary. The individual playing Magic also provided occasional direction to the crew if they became lost.

The two controlling agencies were seated behind the cockpit and monitored the mission's progress. The experimental observer made notes and facilitated the crew occasionally if any problems arose, such as pointing-out any deviation from the requested altitude or speed.

Each crew participated over a period of two days (see Table 2 for schedule). A few days prior to the experimental sessions pilots received an informational mail-out

(Appendix A) describing the purpose of the study, a schedule of events, a brief description of the DVI interface, as well as a list of the vocabulary.

Table 2

Schedule of Experimental Trials

DAY 1		DAY 2	
0800	Arrive, sign-in Introductions	0800	Arrive, sign-in
0820	Introduction to Simulator Familiarity Flights	0815	New CRM review Retrain Verbex
1115	Break	1115	Break
1130	Manual Trial #1 (Experiment 1)	1130	DVI Trial #1 (Experiment 1)
1215	Questionnaire	1215	Questionnaire
1230	Lunch	1245	Lunch
1300	Manual Trial #2 (Experiment 1)	1330	DVI Trial #2 (Experiment 1)
1345	Questionnaire	1415	Questionnaire
1400	Manual Detection Trial (Experiment 2)	1445	Break
1430	Introduction to DVI	1500	DVI Detection Trial (Experiment 2)
1455	Break	1530	Final Questionnaire and Debrief
1505	Train Verbex System	1615	End of Day
1530	Introduce new CRM Familiarization with DVI and CRM in Simulator		
1700	End of Day		

Day 1. Pilots' background information and informed consent (Appendices B & C, respectively) were collected at the beginning of the first day, followed by an overview of the flight simulator, a familiarization flight to become comfortable with the simulator's flight dynamics, a briefing regarding the purpose of the study, and a detailed description of the format of the missions. Several practice flights facilitated by the domain expert were then performed for the purpose of insuring that all flight requirements and communications with controlling agencies were being executed appropriately and that the crew was familiar with the mission. Two trials (missions), lasting approximately 20 minutes using the traditional (manual) cockpit were performed followed by a manual detection task trial (Experiment 2). During the manual trials pilots interacted with CDUs

using the touch-activated bezels formatted to look and react like those used in the Griffon.

Following the experimental trials a brief introduction to DVI was given, including an explanation of the syntax development process and rationale, an explanation of the feedback system, followed by voice training of the Verbex System which lasted approximately 30 minutes. The Verbex System training involved sitting at a computer console and reading aloud all of the words used in the DVI prototype, as well as phrases which allowed the system to hear the words in different orders. Afterwards the prototype CRM model used in this study was described, which simply involved the FP taking over all communications with Zero as well as being responsible for changing the heading needle to the next waypoint. The NFP was still responsible for communications with Magic as well as navigation. Pilots were instructed to insure that good communication between the crew be maintained. The crew was given an opportunity to practice using the DVI system while seated in the cockpit (not-flying).

Day 2. A review of the DVI CRM used for the experimental trials was given, followed by a second training of the Verbex system in order to insure good recognition accuracy. Practice missions were flown facilitated by the domain expert in order to insure that the crew was comfortable with the syntax, use of the DVI system, as well as the DVI CRM. Two DVI experimental trials were flown during the day, followed by the DVI detection trial (Experiment 2). During DVI trials pilots interfaced with the CDUs using DVI whenever possible, and used the manual touch-activated bezel for functions that were not implemented as DVI commands. At the end of the day a debriefing was given of the experiment (see Appendix D), including an explanation of the objective

measures gathered, expected results, as well as allowing the crew an opportunity to make comments regarding the study, and their experiences throughout the two day period.

Procedure

All participants flew the manually configured cockpit the first day, followed by the DVI configured cockpit the second day. The decision was made not to counterbalance for order of presentation, due to the differential amount of experience all crewmembers had using DVI versus manual input (manual cockpit 120-1100 hours, DVI cockpit 2-3 hours). Having crews adapt to the simulators flight dynamics, experimental tasks, new CRM, and use of DVI would have been too overwhelming for the first day of trials. Therefore the first day of trials was spent adapting to the flight dynamics, and experimental tasks using the manual input system and CRM that the pilots were familiar with, and the second day of trials introduced DVI and the new CRM.

For both the manual and DVI conditions, pilots were seated in their typical configuration for the first experimental trial, that is with the most senior crewmember acting as co-pilot and junior member as pilot, followed by a role reversal for the second experimental trial.

Each crew was given a maximum of 10 minutes before each trial to prepare their flight plan. They were provided with a new map, new flight plan data, and a copy of the mission scenario (see Appendix E), which remained constant for all missions. Maps used the military grid reference system as seen in Appendix F, in which grids are labeled with numbers along each axis.

Once comfortably seated in the cockpit, an audio check was executed, followed by calibration of the head tracker. Calibration of the head tracker was obtained by

recording both pilots' head position while looking straight ahead out of the cockpit, then while looking at the CDUs. Once completed, the crew was given a maximum of 2 minutes to input their flight plan and communication information, and prepare for take-off. Experimental data collection began at this time. Following each experimental trial a modified version of the NASA TLX workload questionnaire was completed (see Appendix G).

Missions. Four different experimental missions were flown, partially counterbalanced across DVI and manual input conditions. The order of presentation alternated between crews so that one crew would perform missions 1 and 2 for manual trials, and missions 3 and 4 for DVI trials, and the next crew would perform missions 3 and 4 for manual trials, and missions 1 and 2 for DVI trials. A separate mission was flown for all practice sessions. All missions were composed of the same events (2 reconnaissance legs, 2 contacts, etc.), however, routes (waypoints and features) varied. The crew started each mission at the same location (Home), flew directly to the first waypoint, which was the beginning of the first leg of the reconnaissance (recce) mission. They were then required to follow the feature indicated on their flight plan to the next waypoint (the end of the first leg). While following the designated feature their task was to look for any possible contacts (described as some form of burning vehicle or debris). Once a contact was spotted, they were required to gain enough information to file a contact report with Magic. Pilots were instructed to use the SALUTE format for their contact reports, which consisted of naming the Size, Activity, Location, Unit, Time, and any other pertinent information. Towards the end of the first leg of their recce, Magic retasked the crew, by changing the second leg of their mission. Once they received their

retasking information they were to complete the first leg of their recce and go directly to the beginning of the second leg. Their mission remained the same: to follow the main feature given in the retasking (river, coastline, road, etc.), and then to proceed directly home. On their way home magic would inform them of a possible Civilian Search and Rescue mission, and request their endurance and range. Once the crew forwarded this information, they would be informed that they were no longer required for the Civilian Search and Rescue mission and should proceed home. Pilots were instructed to inform both Zero and Magic when they crossed the phase line (a grid line on their map). During each mission one contact was present per leg, varying in type and position. Frequent radio changes were requested by Magic throughout the mission to insure lots of activity with the CDU and DVI interface. Seven different events were time tagged parsing the mission into six different segments used for later analysis. For a complete description of the mission segments see Appendix H.

Results and Discussion

Two sets of analyses were performed. One set of analyses was conducted on the entire data set (CRM uncontrolled) and the other set of analyses was conducted on a reduced data set (CRM controlled). The CRM controlled data set was created by removing time periods from both the FP's and NFP's DVI trials during which the FP inputted DVI commands. In addition, the equivalent commands executed by the NFPs in the manual trials were removed from both FP and NFP's manual trials. This was done to equate the total amount of mission time removed from all trials, and to equate the number of commands executed by the NFPs and FPs (none) across DVI and manual input conditions. To remove the impact of the FPs' interaction with the system, a total of 10

seconds per command was removed (5 secs. before and 5 secs. after the command was received by the system). Using a listwise procedure, sample size was reduced from 12 to 11 for the CRM uncontrolled data set due to missing head-tracker data for the final mission segment for one subject caused by technical difficulties. The CRM controlled data set sample size was reduced by one more subject ($n = 10$) due to missing data for one subject for one mission segment, which was removed as part of the CRM control process. Results for both the CRM controlled and the CRM uncontrolled data sets were most often the same. Therefore, the results discussed pertain to both data sets: any exceptions are noted.

Head Position

Percent head-up, percent CDU, and percent map/instruments time were calculated separately for the FP and the NFP by dividing the amount of time at each head position within a mission segment by the total time for that mission segment. Each of the six data sets (3 CRM controlled, 3 CRM uncontrolled) was subjected to a 2 (Role) X 2 (Input Type) X 6 (Mission Segment) repeated measures ANOVA. The ANOVAs and corresponding means and standard deviations are presented in Appendix I. Results are discussed in terms of the 95% confidence intervals in accord with Loftus and Masson (1994). The 95% confidence intervals are included in all graphs rather than error bars.

Percent Head-Up Time

FPs spent more time looking up per mission segment than NFPs for both manual input and DVI conditions (see Figures 6 & 7). This was expected as FPs are mandated to maintain a head-up and eyes-out posture when flying, whereas NFPs must look down at maps and instruments to navigate. Both FPs and NFPs spent less time looking up during

the first mission segment (start-up) than during any other mission segment. This was also expected: when preparing for take-off both pilots must look down at the CDUs to input flight plan and systems information and must look down at the map to review the flight plan and route.

Flying pilots. As hypothesized, the amount of time FPs spent looking up when using manual input compared to DVI was not significantly different for most mission segments. These results show that while in-flight, FPs maintained a head-up and eyes-out posture regardless of input type. The one exception was for the first mission segment (start-up) where FPs spent significantly more time looking up in the DVI as compared to the manual input condition (see Figures 6 & 7). While on the ground during start-up FPs are required to input information into the CDUs: the DVI system allows FPs to do this while looking up.

Non-flying pilots. As hypothesized, NFPs spent more time looking up while using DVI compared to manual input for most mission segments. The one exception occurred in the CRM controlled data set for the second mission segment (transit to 1st waypoint) where there was no significant difference in the amount of time spent looking up in the DVI as compared to the manual input condition (see Figure 7). Overall, these results show a clear benefit of the DVI system: NFPs were able to input information using DVI while maintaining a head-up posture.

Figure 6. Mean percent head-up time by role, input type and mission segment (CRM uncontrolled).

Figure 7. Mean percent head-up time by role, input type and mission segment (CRM controlled).

Percent CDU Time

Overall, NFPs spent significantly more time than the FPs looking down at the CDUs in both the manual input and the DVI conditions (see Figures 8 & 9). This was expected, as NFPs are responsible for all CDU interactions during flight whereas FPs are mandated to maintain a head-up and eyes-out posture. Both FPs and NFPs spent significantly more time looking down at the CDUs during the first mission segment (start-up) than during any other mission segment. This finding was anticipated as the first mission segment is the period of time on the ground when crews prepare for take-off.

Flying pilots. As predicted, the amount of time FPs spent looking down at the CDUs was not significantly different for the manual input compared to the DVI condition for most mission segments. The one exception was for the first mission segment (start-up) where FPs spent significantly more time looking down at the CDUs in the manual input as compared to the DVI condition (see Figures 8 & 9). These results show that while in-flight FPs maintained a head-up and eyes-out posture regardless of input type. While on the ground during start-up flying pilots are required to input information into the CDUs: the DVI system allows the FP to do this while looking up.

Non-flying pilots. As predicted, NFPs spent significantly more time looking down at the CDUs with the manual input as compared to the DVI condition for all mission segments. This shows that with DVI NFPs were able to input information into the CDUs while maintaining a head-up posture.

Figure 8. Mean percent CDU time by role, input type and segment (CRM not controlled).

Figure 9. Mean percent CDU time by role, input type and mission segment (CRM controlled).

Percent Map/Instruments Time

Overall, NFPs spent significantly more time than FP looking down at the map/instruments (see Figures 10 & 11). This difference occurred in all mission segments and in both the manual input and DVI conditions. This finding was expected as NFPs are responsible for navigation, which involves the interpretation of maps.

Flying pilots. The amount of time FPs spent looking down at their instruments was minimal and not significantly different in the manual input compared to the DVI condition for any mission segment. This result was predicted as FPs are mandated to maintain a head-up and eyes-out posture and as such, the time spent looking at their instruments is kept to a minimum regardless of input type. Note that FPs spent significantly more time looking at their instruments during the first mission segment (start-up) compared to the other five mission segments for both the manual input and the DVI conditions. Once again this is due to FPs inputting information into the CDUs during start-up, and DVI allowing them to maintain a head-up posture.

Non-flying pilots. Surprisingly, NFPs spent significantly more time looking at map/instruments with the manual input compared to the DVI condition for three of the six mission segments. With the CRM uncontrolled data set (see Figure 10), NFPs spent more time looking at map/instruments with the manual input compared to the DVI condition for mission segments 3, 5, and 6, with mission segment 4 being borderline significant. For the CRM controlled data set (see Figure 11), NFPs spent more time looking at map/instruments with the manual input compared to the DVI condition for mission segments 4, 5, and 6, with mission segment 3 being borderline significant in the same direction, and mission segment 2 in the opposite direction (more time spent looking

at the map/instruments in the DVI compared to the manual input condition). The impact of input type on percent map/instruments time suggests that NFPs' overall memory and information processing demands are reduced when using DVI compared to manual input. This allows map/instrument information to be attained more efficiently resulting in the reduction in the amount of time required to look at these navigation tools.

Figure 10. Mean percent map/instruments time by role, input type and mission segment (CRM uncontrolled).

Figure 11. Mean percent map/instruments time by role, input type and mission segment (CRM controlled).

Subjective Workload Results

Participants ($n = 12$) provided subjective workload ratings after each manual input and DVI experimental trial. Ten types of workload were rated for each of three mission segments on a scale from 0 (low) to 10 (high) (see Appendix G). One workload type (your performance) was removed from the analysis as it was deemed not to be a valid dimension of workload. Ratings for the nine workload types were collapsed across the three mission segments for analysis. Workload ratings were subjected to a 2 (Role) X 2 (Input Type) X 9 (Workload Type) repeated measures ANOVA. The ANOVAs and corresponding means and standard deviations are presented in Appendix I. Results are discussed in terms of the 95% confidence intervals in accord with Loftus and Masson (1994). The 95% confidence intervals are included in all graphs rather than error bars.

Flying pilots. FPs rated visual demand as significantly higher for the manual input compared to the DVI condition, whereas ratings for the other eight workload types, including auditory demands, were not significantly different (see Figure 12). It is not surprising that visual demands were rated higher with manual input compared to DVI due to the complex menu architecture associated with the CDUs. It is noteworthy, however, that aspects of workload were not rated higher in the DVI condition even though the FPs took on additional duties during the DVI trials. The fact that FPs' ratings of workload were not significantly different may be indicative of a reduction of resource demands associated with DVI. This finding provides subjective evidence that FPs are able to take on extra tasks with the DVI system without significantly increasing workload.

Non-flying pilots. NFPs rated five of the workload types (visual demands, physical demands, time pressure, anxiety, and global workload) as significantly higher when using manual input compared to DVI (see Figure 13). These results indicate that NFPs felt that DVI required fewer resources compared to manual input. Because workload ratings are not controlled for the change in CRM, the difference in subjective workload may either be due to differences between the two input systems, to the FPs taking over some of the commands, or a combination of the two. Experiment 2 examines workload objectively.

Figure 12. FPs' Mean workload ratings by workload type and input type.

Figure 13. NFPs' mean workload ratings by workload type and input type.

Summary of Experiment 1 Results

The head position and subjective workload results showed that FPs were able to take on extra tasks using the DVI system without having any detrimental effects on head-position or perceived workload. While flying, the amount of time FPs spent looking up, looking at the CDUs, and looking at instruments did not differ when using DVI compared to manual input (see Table 3). This shows that FPs were able to input information into the CDUs while flying using the DVI system, while maintaining their mandated head-up and eyes-out posture. While on the ground during start-up, FPs spent more time looking up, less time looking down at the CDUs, and the same amount of time looking at instruments using DVI compared to manual input. These findings show that while on the ground when FPs are required to input information into the CDUs, the DVI system allows the FP to do this while looking out. In terms of workload, FPs rated the visual demands associated with the manual system as higher than with the DVI system, and all other workload dimensions as not differing between the two input types. These findings are noteworthy, as one would expect workload to increase in the DVI condition because FPs took on additional duties during the DVI trials. The fact that FPs' ratings of workload were not significantly different may be indicative of a reduction of resource demands associated with DVI.

For NFPs both head position and subjective workload results showed that NFPs benefited by using DVI compared to manual input. When using DVI, NFPs looked up more, looked down at the CDUs less, and with half the mission segments looked down less at map/instruments (see Table 3). DVI is clearly advantageous to NFPs as it allows them to look out at the external scene more compared to manual input. The same pattern

of head position results occurred for the CRM controlled data set as the CRM uncontrolled data set. This shows that the NFPs' ability to look up more in the DVI compared to the manual input condition was not simply a consequence of having the FPs take over commands. In terms of subjective workload, NFPs rated DVI as lower than manual input in terms of visual demands, physical demands, time pressure, anxiety, and global workload. Because workload ratings are not controlled for the change in CRM, the difference in subjective workload may either be due to differences between the two input systems, FPs taking over some of the commands, or a combination of the two. Experiment 2 examines workload objectively using a secondary target detection task.

Table 3

Summary of Head Position Findings

	Percent head-up time	Percent CDU time	Percent map/instruments time
Flying pilot	All segments n.s. except segment 1 where DVI > manual	All segment n.s. except segment 1 DVI < manual	All segments n.s. except segment 1 > others for both DVI and manual
Non-flying pilots	All segments DVI > manual except segment 2 n.s. when CRM controlled	All segments manual > DVI	For 3 of 6 segments manual > DVI

Experiment 2

DVI and Attention

The present experiment was designed to assess the impact of DVI on the attentional demands placed on the FP and the NFP in the Griffon. Few studies have been conducted on the relationship between attention and DVI. One study conducted by Baber, Mellor, Graham, Noyes, and Tunley (1996) examined the impact of attentional workload on speech production and recognition. Two possible types of workload interference were identified: mechanical (physical changes in speech production) and psychological (possible competition between speech and other tasks). Workload was defined as the “amount of activity a person is required to perform per unit time”. In the first experiment, fifteen participants were required to read license plates from a video recording using the ICAO alphabet and digits (0-9). There were two panning rates used in the video (20 and 33 plates per minute). After each video, participants completed a modified NASA TLX subjective workload rating. At word level accuracy, there was a significant difference between the slow and the fast conditions. There were also significant differences in the word errors. The principal cause of speaker error appeared to be erroneous selection of vocabulary items in the fast condition (e.g., “dog” instead of “delta”). The NASA TLX data showed that the participants judged the fast condition to be significantly more difficult than the slow.

Baber et al.'s (1996) second experiment explored the effects of a secondary task on speech recognition. The primary task consisted of two stages: target identification and report filling. Participants acquired a target on a screen by moving a cursor onto one of four possible shapes and then had to zoom in to obtain more information (e.g. colour).

After identifying the target, participants filled-in a report describing the object.

Participants used each of three input devices (min-trackball, function keys, speech input).

A secondary task, mental arithmetic, was presented aurally every 1-5 seconds at two levels of workload (no carry-over versus carry-over required). The results showed speech input to be significantly slower than the other two input devices for both target selection and filling. Recognition accuracy at the various workload levels was only significantly different between the no load and the high load conditions. The authors concluded that workload impacts the production of consistent speech, which leads to reduced accuracy, and that the problem is exacerbated by the additional effect on human performance such as the use of illegal vocabulary.

The conclusion that workload impacts on the production of speech is of interest, and may suggest the need for manual input to be maintained as a back-up system to DVI in high workload situations. As for the use of illegal vocabulary under high workload conditions, it may be useful to conduct a study examining the impact of DVI once it has become highly practiced, in order to determine whether the same trend of results would occur, or whether the vocabulary items would become more easily accessible under high workload situations with practice. Baber et al.'s (1996) results showing speech recognition to be slower than the other two input devices may, however, not translate to the impact of DVI within the Griffon cockpit compared to that of manual input. DVI may decrease the time taken to perform some tasks by allowing pilots to bypass the complex menu architecture currently used in the CDUs, and this in turn may reduce the workload level associated with the task.

Enterkin (1991) conducted a study that required participants to perform a visual tracking task on a HUD using the flight stick in a cockpit simulator. Subjects were asked to repeat digit strings presented on the HUD into their microphone and also to assess visual feedback on a liquid crystal display readout. The input mode for data correction, DVI or keypad was assessed across groups. Subjective ratings were also measured (NASA TLX). The results showed voice correction took consistently longer than keypad correction. In terms of overall workload scores, no statistically significant difference was shown between input modes. However, in terms of the individual workload dimensions, Enterkin reports that both input modes were rated relatively high on mental demand, while voice correction was rated significantly lower on the dimension of effort.

While these results are of interest, the conclusion that speech input takes longer than keypad input does not consider the impact on head-up time, nor the impact of the current CDU interface which requires lengthy interactions. The result that voice correction was rated lower in terms of effort seems to support the contention of a possible workload benefit using DVI, however, the overall workload results are inconclusive.

Bortolussi and Vidulich (1991) examined the effect of response modality on time-sharing performance using a secondary probe task. The experiment was performed in the NASA-Ames' Interchangeable Cab facility; the aircraft simulated was a single-pilot scout attack helicopter, and the participants wore head-up displays. A moving map display was used to navigate a 4 km by 4 km terrain database. Each flight trial lasted 2-5 minutes, and consisted of six phases (Hover, Low level transit, Combat, Hover, Low level transit, Hover). The experiment compared the interference of manual and speech responses during continuous flight control. A secondary target task was used to evaluate the

interference. One of two possible missile threats (Sam-6 and Sam-9) was presented to the pilot. SAM-6 required a manual response (cyclic button) while SAM-9 required a voice response "Flare". To provide a more detailed analysis of predicted interference, a Psychological Refractory Period Paradigm was used. The helicopter unexpectedly pitched down and rolled and the pilot was to bring the aircraft to the previous altitude and attitude as quickly as possible. Either 100 or 300 ms after the aircraft pitched and rolled, the pilot would be presented with one of the two threats and the reaction time was recorded. The results showed a significant main effect for response modality with speech responses being slower than manual responses. There was also a significant Phase x Response Modality interaction, with manual response interference being higher under high workload demands (combat). There was also a significant Response modality x Inter Stimulus Interval (ISI) interaction of the mean decrement scores, suggesting that manual response greatly interferes with manual flight control corrections in response to unusual attitudes especially when the two stimuli occur near simultaneously. Additionally, the duration of interference was less in the speech modality condition.

The results provide somewhat of a mixed interpretation, in that overall speech response was slower, however, the duration of the interference was less. Moreover the manual response condition showed greater interference under high workload demands which are the periods of greatest safety concerns.

The one study that has examined the implementation of DVI within a multi-crew environment was performed by Collins, Ball, and Manning (1997). The authors report on the integration of DVI into the helicopter cockpit as part of the Britain's Day, Night and All Weather program. The study compared the use of manual controls and DVI by a

pilot and commander during nap of the earth missions in a simulated operational environment. Four missions were flown by each of five crews (attack, airborne observation post, reconnaissance, and battle plan delivery). Feedback was provided to both the pilot and the commander through talkback over the headset. For each mission, position and flight data were recorded and video recordings were taken. To measure workload an in-house workload scale was employed using the DERA Continuous Subjective Assessment of Workload. Immediately after each trial the crew gave their workload ratings when a video of their flight was replayed for them. Collins et al. chose a qualitative analysis of the data. The results showed DVI to be especially beneficial during high workload periods when the pilot's were concentrating on the display and hands and eyes were busy. In addition, most participants reportedly liked the system, and several suggested that additional controls such as anti-collision lighting, windshield wipers, and multi-page displays be added to DVI functionality.

The effects of DVI compared to manual input on attentional demands, in addition to having implications for aviation applications, may also have implication for in-vehicle systems such as hands-free cellular phones, voice activated navigation systems, AutoPCs etc. Lee, Caven, Haake, and Brown (2000) examined the effects of speech-based e-mail on drivers' attention to the roadway. Twenty-four drivers drove a series of 5-7 minute scenarios in a medium fidelity driving simulator. Measures of reaction time to the braking of a lead vehicle, subjective mental workload and subjective measures of drivers' situation awareness were collected in an attempt to determine the cognitive demands associated with a simple versus complex e-mail system while driving through a simple or complex environment. Results showed drivers responded more slowly when driving

through the complex compared to the simple environment, however, system complexity did not have a statistically significant effect on reaction time. In terms of the subjective ratings, the workload measures were higher for the complex versus the simple system and were perceived as more distracting, whereas the complexity of the driving environment did not have an impact on the subjective workload. The authors concluded, based on the workload data, that a speech-based interface can distract drivers and can meaningfully affect driving safety. Unfortunately this study did not compare speech-based e-mail to a manual system, and therefore no conclusions can be drawn as to the relative effect of a speech-based interactions compared to manual interactions.

Carter and Graham (2000) also examine the effects of speech-based controls on workload while driving. The authors compared four different types of controls (standard manual controls, manual steering wheel button controls, voice controls with feedback, and voice controls with no feedback) for operating an in-car entertainment system. Thirty-two subjects performed a PC based tracking task that mimicked driving either alone (baseline) or with a concurrent visual probe task (dual task). RMS error for the tracking task, reaction time to the probe task, and subjective workload was measured. Results showed driving performance (tracking task) to be significantly better with voice controls over manual controls, whereas reaction times to the probe task were shortest for the standard controls followed by the voice controls, and steering wheel controls. Voice controls were rated as lowest in terms of workload, and were also rated as most likeable. Based on the results of the tracking task the authors conclude voice controls to be less detrimental to driving than manually operated in-car systems.

In sum, although the above studies shed light on some of the issues involved in the implementation of DVI, none have provided insight into the impact of DVI on workload within a multi-crew environment. Baber et al. (1996) examined the impact of workload on voice recognition rather than the impact of voice recognition on workload, and showed speech accuracy deteriorates under high workload conditions. However, participants received very little practice in this study with DVI, and therefore no clear conclusions regarding speech accuracy on long-term use can be made.

The two studies comparing the impact of DVI versus manual input on workload used solely subjective measures (Enterkin, 1991; Collins et al., 1997). Enterkin found no statistically significant difference between workload ratings, whereas Collins et al. found DVI to be especially beneficial during high workload situations. The one study (Bortolussi & Vidulich, 1991) utilizing an objective measure of workload (secondary task performance) showed manual input interfered in secondary task performance longer under high workload situations than DVI. Therefore, no clear conclusions regarding the impact of DVI on workload have been made. In fact, no study has evaluated the impact of DVI versus manual input within a multi-crew environment using an objective measure. The current study will attempt to do so.

The present experiment was designed to assess the impact of DVI on attentional demands placed on the FP and NFP in the Griffon helicopter. To do this, pilots were required to perform a secondary visual and auditory detection task, while flying operational missions. The secondary task provides a measure of the spare resources left over from the primary task of flying with the two input systems. In that, if the residual resources from the primary task increase, so too will performance on the secondary task.

The visual component of the detection task was included in order to provide a converging measure of head-up time as well a measure of visual resources available when using DVI compared to manual input. An increase in head-up time or an increase in available visual resources is expected to produce an increase in the number of visual targets detected, as well as a decrease in latencies to visual targets. The auditory component was included in order to provide insight into the impact of DVI versus manual input on auditory demands experienced in the Griffon helicopter. DVI may increase auditory demands in the cockpit, thereby decreasing the number of auditory targets detected, as well as a increasing reaction time to auditory targets. The detection task as a whole is anticipated to provide an index of the resources required using the DVI system compared to the resources required using the manual input system.

Method

Participants

The same twelve pilots from Experiment 1 also participated in Experiment 2.

Materials and Procedures

All materials and procedures remained the same as in Experiment 1, except for the following differences. The manual input detection trials were performed at the end of day 1, whereas the DVI detection trials were performed at the end of day 2 (see Table 2 above). The missions were completely counterbalanced across DVI and manual input conditions, so that three crews received one order, and three crews received the opposite order, alternating between the two orders. Two experimental missions, similar to those in Experiment 1, were flown with a concurrent secondary auditory and visual detection task. Before each of the two trials participants were instructed to consider the mission as their primary task, and target detection as their secondary tasks. They were instructed to

concentrate on performing their mission, however, they were to respond to the visual and auditory targets as quickly and as accurately as possible. To respond to the targets the NFP clicked a switch with his/her left hand thumb, due also to having to manipulate the map, and the FP clicked a trigger on the cyclic using his/her trigger finger. The pilot seating remained constant for both trials, with the most senior crewmember acting as co-pilot, and junior member as pilot.

Before each trial, pilots were given an example of each target, followed by a baseline condition that lasted approximately 10 minutes. During the baseline condition the crew was seated in the cockpit with the visual scene on, as well as the ambient background noise, and were asked to respond to the visual and auditory targets as quickly and as accurately as possible. The baseline was used as a measure of single task performance against which the dual-task could be compared. After the baseline condition, the crew was given the usual preparation time (10 minutes) to plan their mission, followed by an audio check and head tracker calibration. The targets began once the crew was given 2 minutes to input their flight data.

The detection targets were presented at intervals of 8 seconds $\pm$ a random variability of 4 seconds. The persistence of the visual target was 500 msec and could be described as a glowing green orb (full colour saturation) positioned in the center of projection screen and subtending 3-degree (approx.) field of view. The audio target also lasted 500 msec and could be characterized as a distinctive "buzz". The detection task continued for approximately 16 minutes, with an equal number of visual and auditory targets being presented in random order. The balance of the mission (up to 4 minutes) was completed without targets.

Results and Discussion

As in Experiment 1, two sets of analyses were performed. One set of analyses was conducted on the entire data set (CRM uncontrolled) and the other set of analyses was conducted on a reduced data set (CRM controlled). Results for both the CRM controlled and the CRM uncontrolled data sets were most often the same. Therefore, the results discussed pertain to both data sets: any exceptions are noted. Results are discussed in terms of 95% confidence intervals in accord with Loftus and Masson (1994). The 95% confidence intervals are included in all graphs rather than error bars.

Head Position

Head position was examined in Experiment 2 to determine whether or not results of Experiment 1 would be replicated and to confirm that the visual and auditory detection task did not fundamentally change the pilots' behaviour. As in Experiment 1, percent head-up, percent CDU, and percent map/instruments time were calculated by dividing the amount of time at each head position within a mission segment, by the total time for that mission segment. Each of the six data sets (3 CRM uncontrolled, 3 CRM controlled) was subjected to a 2 (Role) X 2 (Input Type) X 6 (Mission Segment) mixed design ANOVA with Role as a between subjects factor and Input Type and Mission Segment as within subjects factors. The ANOVAs and corresponding means and standard deviations are presented in Appendix J.

Percent Head-Up Time

Flying pilots. Similar to Experiment 1, the amount of time FPs spent looking up while using manual input compared to DVI was not significantly different for 4 of the 6 mission segments. For 2 mission segments (start-up, and transit to 1st recce) FPs spent

significantly more time looking up using DVI compared to manual input (see Figures 14 & 15).

Non-flying pilots. As in Experiment 1, NFPs spent more time looking up while using DVI compared to manual input for most mission segments. The one exception was for the CRM controlled data set, there was no significant difference in the amount of time spent looking up during the fourth mission segment (transit between legs) (see Figure 15). These results replicate the findings in Experiment 1, and show a clear benefit for NFPs using the DVI system: NFPs were able to input information into the CDUs using DVI while maintaining a head-up posture.

Figure 14. Mean percent head-up time by role, input type, and mission segment (CRM uncontrolled).

Figure 15. Mean percent head-up time by role, input type, and mission segment (CRM controlled).

Percent CDU Time

Flying-pilots. As in Experiment 1, the amount of time FPs spent looking down at the CDUs was not significantly different for manual input compared to DVI for most mission segments (see Figures 16 & 17). The one exception was the first mission segment (start-up) where FPs spent significantly more time looking down at the CDUs with manual input compared to DVI. These results replicate the findings in Experiment 1 and show that while in-flight, FPs maintained a head-up and eyes-out posture regardless of input type. While on the ground during start-up flying pilots are required to input information into the CDUs: the DVI system allows the FP to do this while looking out at the external scene.

Non-flying pilots. NFPs spent significantly more time looking down at the CDUs with manual input compared to DVI for most mission segments (see Figures 16 & 17). The one exception was the second mission segment in which NFPs time spent

looking at the CDUs did not differ with the CRM controlled data set (see Figure 17).

This replicates Experiment 1, and shows that with DVI, NFPs were able to input information into the CDUs while maintaining a head-up and eyes-out posture.

Figure 16. Mean percent CDU time by role, input type and segment (CRM uncontrolled).

Figure 17. Mean percent CDU time by role, input type, and mission segment (CRM controlled).

Percent Map/Instruments Time

Flying-pilots. With the CRM uncontrolled data set, FPs spent more time looking down at their instruments while using manual input compared to DVI for 2 of the 6 mission segments (transit to 1st waypoint, and 1st recce – see Figure 18). No significant difference in the amount of time spent looking at instruments existed for 4 mission segments. The same pattern of results occurred with the CRM controlled data set with the exception that only segment 2 (transit to 1st waypoint) was significantly different (see Figure 19). These findings were expected as DVI commands do not relate directly to instruments and are not expected to change the amount of time spent looking at instruments. In addition FPs are mandated to maintain a head-up and eyes out posture and therefore keep the amount of time spent looking at instruments to a minimum.

Non-flying pilots. NFPs time spent looking at map/instruments was not significantly different for 5 of the 6 mission segments (see Figs 18 & 19). Only

segment 2 (transit to 1st waypoint) showed a difference, with NFPs spending more time looking at map/instruments with manual input compared to DVI. Overall, these results support the contention that input type does not affect time NFPs spent looking at map/instruments, as input type does not relate directly to these navigation tools.

Figure 18. Mean percent map/instruments time by role, input type, and segment (CRM uncontrolled).

Figure 19. Mean percent map/instruments time by role, input type, and mission segment (CRM controlled).

Summary of Head Position Results

Head position results for Experiment 2 replicate Experiment 1, and show that adding the secondary target detection task did not change the fundamental behaviour of pilots in terms of head position. As in Experiment 1, FPs were able to take on extra tasks using the DVI system without having any detrimental effects on head-position. While flying, the amount of time spent looking up, looking at the CDUs, and looking at instruments did not differ when using DVI compared to manual input (see Table 4). This shows that FPs were able to input information into the CDUs with the DVI system while maintaining their mandated head-up and eyes-out posture. While on the ground during start-up, FPs spent more time looking up, less time looking down at the CDUs, and the same amount of time looking at instruments using DVI compared to manual input. These

findings show that, while on the ground, DVI allows FPs to maintain a head-up and an eyes-out posture while inputting information into the CDUs. Conversely, as in Experiment 1, NFPs' head position did change as a function of input type (see Figure 4). With DVI, NFPs spent more time looking up, less time looking at the CDUs, and the same amount of time looking at map/instruments. As in Experiment 1, the conclusion is the same: DVI clearly benefits NFPs in terms of increasing head-up time.

Table 4

Summary of Head Position Findings

	Percent head-up time	Percent CDU time	Percent map/instruments time
Flying pilot	All segments n.s. except segment 1 & 2 where DVI > manual	All segment n.s. except segment 1 DVI < manual	All segments n.s. except segment 2 & 3 DVI < manual
Non-flying pilots	All segments DVI > manual except segment 4 n.s. when CRM controlled	All segments manual > DVI	All segments n.s. except segment 2 DVI < manual

Latency Results

An objective measure of workload was obtained by subtracting single-task latencies (target detection baseline) from the corresponding dual-task latencies (target detection plus mission scenario). Decrement scores between single-task and dual-task performance are shown graphically in Figures 20-21. The larger the bars the greater the workload demands associated with the primary task (performing the mission using each input system). Latencies were analyzed using a 2 (Role) X 2 (Target Type) X 2 (Input Type) X 2 (condition) mixed design ANOVA, with Role as the between subjects factor and all others as within subjects factors. The ANOVAs and corresponding means and

standard deviations are presented Appendix J. Response latencies over 3 standard deviations away from the mean were removed from the analysis, as well as response latencies of less than 100 milliseconds.

No significant differences by Role or Target Type occurred across the single-task baseline conditions. Therefore, any single-to-dual-task differences are attributed to differences associated with the primary task (performing the mission using each input system).

Flying pilots. FPs latency decrement scores were significantly larger in the DVI compared to the manual input condition for auditory targets, and borderline significant for visual targets (see Figure 20 & 21). These findings suggest that FPs' workload levels increased while using DVI compared to manual input. This same pattern of results occurred for both the CRM uncontrolled and the CRM controlled data sets, therefore the increase in workload cannot be attributed to the time periods when the FPs were interacting with the DVI system: the same pattern of results occurred when the FPs interactions with the DVI system were excluded from analysis.

Non-flying pilots. NFPs latency decrement scores were not significantly different for the auditory targets, whereas for the visual targets decrement scores were borderline significant with manual decrement scores being larger than DVI decrement scores (see Figures 20 & 21). This suggests that NFPs experienced a benefit in terms of visual resources from the DVI system.

Figure 20. Mean latency difference by role, input type and target type (CRM uncontrolled).

Figure 21. Mean latency difference by role, input type and target type (CRM controlled).

Summary of Latency Results

The detection task latency results showed that FPs were negatively impacted by the DVI system in terms of available resources. Conversely, NFPs benefited from the DVI system in terms of visual resources. To determine whether or not a speed accuracy trade-off occurred accuracy results were examined.

Overall Mean Percent Correct Responses (Accuracy Results)

Mean percent correct decrement scores between single task (target detection baseline) and dual task (target detection plus mission scenario) performance are shown graphically in Figures 22 and 23. The bars represent accuracy deficits during dual-task performance: the larger the bar, the greater the deficit. Mean percent correct responses were analyzed using a 2 (Role) X 2 (Target Type) X 2 (Input Type) X 2 (Condition) mixed design ANOVA, with Role as the between subjects factor and all others as within subjects factors. The ANOVAs and corresponding means and standard deviations are presented in Appendix J.

Flying pilots. As seen in Figure 22 and 23, the same pattern as the latency results occurred for the accuracy results. For FPs, the manual input condition had less accuracy decrement than the DVI condition for both visual and auditory targets. These results suggest that no speed accuracy trade-off occurred: decrements in speed and accuracy mirrored one another indicating poorer performance in both measurements. Overall resource demands seem to be higher for FPs when using DVI compared to manual input.

Non-flying pilots. Results for the NFPs also mirrored the latency pattern of results. Manual percent correct decrement scores were significantly higher compared to DVI for visual targets. As above, this indicates that no speed-accuracy trade-off

occurred: the same pattern of deficits occurred in each measurement form. This finding indicates that NFPs visual demands are less with DVI compared to manual input.

Figure 22. Mean percent correct response difference by role, input type, and target type

CRM uncontrolled).

Figure 23. Mean percent correct response difference by role, input type, and target type

(CRM controlled).

Mean Percent Correct Responses by Head Position

To determine the accuracy rates of visual and auditory targets for each head position, mean percent correct responses were analyzed separately for each of the 3 head positions. Because FPs keep their time looking down at the CDUs or their instruments to a minimum, analysis of these two head positions was only conducted on NFPs. For the head-up position, a 2 (Role) X 2 (Input Type) X 2 (Target Type) mixed design ANOVA was performed with Role as a between subjects factor and Input Type and Target Type as within subjects factors. For the CDU and map/instruments head positions, 2 (Input Type) X 2 (Target Type) repeated measures ANOVAs were performed for NFPs. The ANOVAs and corresponding means and standard deviations are presented in Appendix J. Single task head position was not used as a baseline, as pilots were told to look straight ahead at all times, and respond as quickly and as accurately to the targets. Consequently, mean percent accuracy results by head position are not decrement scores, but are the percent of targets accurately responded to per condition.

Mean Percent Correct Response while Looking Up

Flying pilots. When looking up, FPs were more accurate at responding to both visual and auditory targets in the manual input compared to the DVI condition (see Figure 24 & 25). These findings suggest that FPs' mental workload increased while using DVI compared to manual input. This same pattern of results occurred for both the CRM uncontrolled and the CRM controlled data sets, therefore the increase in workload cannot be attributed to the time periods when the FPs were interacting with the DVI system: the same pattern of results occurred when the FPs interactions with the DVI system were excluded from analysis.

Non-flying pilots. When looking up, NFPs were significantly more accurate at responding to visual targets with DVI compared to manual input (see Figure 24 & 25). This shows that DVI not only increased the amount of head-up time but also the accuracy of detecting visual targets once looking up. That is, DVI resulted in a decrease in visual processing demands for NFPs. The accuracy of responding to auditory targets was not significantly different for manual input versus DVI, indicating that the decrease in resources associated with DVI for the NFP may specifically relate to the visual modality.

Figure 24. Mean percent correct responses while head-up by role, input type, and target type (CRM uncontrolled).

Figure 25. Mean percent correct responses while head-up by role, input type and target type (CRM controlled).

Mean Percent Correct Responses while Looking at the CDUs

Non-flying pilots. As seen in Figure 26 and 27, no significant differences in detecting visual and auditory targets occurred while NFPs were looking at the CDUs in the manual input versus DVI condition. This finding indicates that NFPs while looking at the CDUs were able to respond to both visual and auditory targets equally well using both input types.

Figure 26. Mean percent correct responses for NFPs while looking at CDUs by input type, and target type (CRM uncontrolled).

Figure 27. Mean percent correct responses for NFPs while looking at CDUs by input type, and target type (CRM controlled).

Mean Percent Correct Responses while Looking at Map/Instruments

Non-flying pilots. As seen in Figure 28 and 29, no significant differences in accuracy occurred while looking at map and instruments for visual and auditory targets, with manual input compared to DVI. This finding indicates that NFPs while looking at the map and instruments were unaffected by input type.

Figure 28. Mean percent correct responses for NFPs while looking at map/instruments by input type, and target type (CRM uncontrolled).

Figure 29. Mean percent correct responses for NFPs while looking at map/instruments by input type, and target type (CRM controlled).

Summary of Mean Percent Correct Responses

The detection task accuracy results showed that FPs were negatively impacted by the DVI system in terms of available resources. Conversely, NFPs benefited from the DVI system in terms of visual resources. The same pattern of results occurred when pilots were looking up as in the overall accuracy findings. That is, FPs were more accurate at responding to visual and auditory targets in the manual input compared to the DVI condition, and NFPs were more accurate at responding to visual targets with DVI compared to manual input. When NFPs were looking at the CDUs or at map/instruments no significant differences in accuracy occurred for visual and auditory targets, with manual input compared to DVI.

General Discussion

The goal of the current research was to determine the effects of implementing a DVI system in the CH-146 Griffon helicopter. Specifically, the aim was to determine how the implementation of a DVI system in the Griffon would affect head position and workload compared to the current manual input system.

Head Position

For NFPs, DVI was predicted to increase head-up time, and decrease the amount of time spent looking at the CDUs. This pattern of results was predicted as it was believed that DVI would allow NFPs to input information into the CDUs without looking down. Results from Experiments 1 and 2 support these hypotheses. NFPs looked up more and specifically, looked at the CDUs less with DVI compared to manual input. This finding is important in that it confirms that NFPs were able to input information into the CDUs while maintaining a head-up and eyes-out posture. In terms of the amount of time NFPs spend looking at maps and instruments, DVI was predicted to have no effect compared to manual input, because DVI does not directly interact with these navigation tools. Results for Experiment 1 and 2 partially supported this hypothesis: three-out-of-six mission segments in Experiment 1, and five-out-of-six mission segments in Experiment 2 showed no difference for DVI and manual input in time spent looking at maps and instruments for NFPs. The other mission segments showed a decrease in the amount of time spent looking at maps and instruments with DVI compared to manual input. There are several possible explanations why NFPs looked at map and instruments less. The most plausible explanation is that NFPs looked out more with DVI, leading to an increased level of spatial awareness, and consequently a decreased need to look at

navigation tools such as maps. This finding is important in that it supports the contention that DVI, by increasing head-up time, increases flight safety by allowing NFPs to maintain a high level of awareness of their position in space. An alternative explanation is that NFPs' memory capacity and information processing resources are being used less with DVI. On this view, crucial map and instrument information is acquired and maintained more easily, reducing the amount of time required to acquire this information. In either case, DVI is clearly benefiting NFPs by allowing them to look up more, look at the CDUs less, and at times look at maps and instruments less.

For FPs, DVI was predicted to have no effect on head-up time, no effect on the amount of time spent looking at CDUs, and no effect on the amount of time spent looking at instruments compared to manual input. This pattern of results was predicted as FPs are mandated to maintain a head-up and eyes-out posture at all times regardless of input type. Head position results from both Experiment 1 and 2 support this hypothesis. While flying, the amount of time spent looking up, looking at the CDUs, and looking at instruments did not differ when using DVI compared to manual input for most mission segments. These findings show that FPs were able to take on extra tasks using DVI without having any detrimental effects on head-position.

No predictions were made concerning head positions for FPs and NFPs while on the ground during start-up. Results showed both FPs and NFPs spent more time looking up, less time looking down at the CDUs, and the same amount of time looking at the map and instruments using DVI compared to manual input. These findings show that while on the ground, the DVI system allows pilots to enter information into the CDUs while looking out at the external scene more compared to when using manual input. Although

there is no need to look at the external scene while on the ground, these results indicate that using the DVI system automatically promotes a head-up position.

Workload

Although the head position results are informative, they do not give an indication of the processing demands required by both the manual input and DVI systems: looking up more does not necessarily mean you are processing more visual information. In Experiment 2, the workload levels associated with DVI versus manual input were assessed using a secondary visual and auditory target detection task. Secondary tasks provide a measure of residual resources left over from the primary task (mission using DVI or manual input), if residual resources increase, so too will performance on the secondary task. The visual component of the target detection task was included in order to provide a converging measure of head-up time as well a measure of visual resources available when using DVI compared to manual input. An increase in head-up time or an increase in available visual resources is expected to produce an increase in the number of visual targets detected, as well as a decrease in reaction time to visual targets. The auditory component was included in order to provide insight into the impact of DVI versus manual input on auditory demands experienced in the cockpit. DVI may increase auditory demands in the cockpit, thereby decreasing the number of auditory targets detected, as well as a decreasing reaction time to auditory targets. The detection task as a whole was anticipated to provide an index of the overall resources required using the DVI system compared to the overall resources required using the manual input system.

The target detection task latency and accuracy results showed that FPs were negatively impacted by the DVI system in terms of available resources. FPs responded

more slowly and less accurately with DVI compared to manual input for both visual and auditory targets, and responded less accurately for both visual and auditory targets while looking up. These results suggest an increase in overall resource demands on the FP associated with DVI compared to manual input. This same pattern of results occurred for both the CRM uncontrolled and the CRM controlled data sets, therefore the increase in workload cannot be attributed to the time periods when the FPs were interacting with the DVI system: the same pattern of results occurred when the FPs interactions with the DVI system were excluded from analysis.

The finding that for FPs DVI caused a decrease in performance compared to manual input for both visual and auditory targets is contrary to what would be expected based on multiple resource theory. According to multiple resource theory humans possess more than a single kind of attentional resource, and an increase in demands of one task will have a detrimental effect on performance of a concurrent task if they share the same resource requirements rather than different. DVI should require the resources associated with auditory perception, verbal working memory, and vocal response (Wickens, 1984), and should therefore increase response latencies and decrease accuracy rates to the auditory component of the target detection task, whereas the visual component should not be negatively affected. The fact that both auditory and visual targets were negatively impacted therefore suggests that for FPs, DVI may be affecting central processing resources. Moreover, the fact that the same pattern of results occurred when the FPs interactions with the DVI system were excluded from analysis indicates that these central processing resources are being used even during periods of time when the FPs are not interacting with the DVI system. One explanation for this pattern of

results is that the deficit in performance during the DVI condition is due to FPs being cognitively engaged with the DVI system. In other words, the mental sets of FPs are shifting from a state of ease and certainty associated with solely being responsible for flying the aircraft, to a state of heightened anticipation and preparation associated with taking on new responsibilities and having to deal with a novel system. Further research is required to examine the effects of familiarity on workload levels for FPs using DVI.

For NFPs the target detection task latency and accuracy results showed that DVI positively impacted NFPs in terms of the availability of visual resources. NFPs responded to visual targets more quickly and more accurately with DVI compared to manual input, whereas no differences occurred for auditory targets. This same pattern of results occurred for both the CRM uncontrolled and the CRM controlled data sets, therefore the decrease in workload cannot be attributed to the reduction of tasks for the NFPs in the DVI conditions.

The finding that NFPs showed an increase in performance for visual targets compared to manual input is somewhat consistent with multiple resource theory. Within a multiple resource model the detection of visual targets and manual input both demand resources associated with visual perception, spatial working memory, and manual response and consequently would be predicted to have a higher level of task interference than the detection of visual targets with DVI. This finding supports the contention that DVI compared to manual input will increase flight safety by improving the NFPs' detection of obstacles in the aircraft's path such as power lines and trees, and will increase mission effectiveness through improved visual detection of contacts during as search and rescue and reconnaissance missions.

Conclusion

The results of the current study provide an initial assessment of the effects of implementing a DVI system within a complex multi-crew environment such as the Griffon helicopter. Unlike most in-vehicle implementations of DVI, interactions with the avionics management system are compulsory, therefore, the question is not whether these interactions should be permitted but rather which input system is the least demanding.

Results indicate that a redistribution of workload between the crew occurred with DVI compared to the existing manual input system. NFPs clearly benefited with DVI compared to manual input, both in terms of increasing head-up time as well as decreasing visual demands. In addition, NFPs showed no change in auditory demands with the use of DVI compared to manual input. Conversely, FP clearly suffered costs when using DVI compared to manual input in terms of both visual and auditory demands. The fact that for FPs, differences as little as a fraction of a second in response times can make the difference between safety and disaster, highlights the need for caution when considering new responsibilities and interfaces for FPs. Based on the findings of the current study it is recommended that the existing CRM model for the CH-146 Griffon helicopter remain unchanged, that is, FPs should focus solely on flying the aircraft leaving all other responsibilities for NFPs. DVI has been shown to increase head-up time, and decrease mental workload for NFPs, and is therefore recommended as an interface for NFPs in the Griffon helicopter. DVI will change the way pilots interact with aircraft systems and each other and should be examined further to ensure that flight safety and mission effectiveness are enhanced.

References

Anderson, T. R. (1998). Applications of Speech Based Control. Presented at Alternative Control Technologies: Human Factors Issues. Brétigny (France) and Ohio (USA): October 1998.

Baber, C., Mellor, B., Graham, R., Noyes, J. M. & Tunley, C. (1996). Workload and the use of automatic speech recognition: The effects of time and resource demands. Speech Communication, 20, 37-53.

Bortolussi, M. R. & Vidulich, M. A. (1991). The effect of speech controls on performance in advanced helicopters in a double simulation paradigm. In International Symposium on Aviation Psychology. Columbus, OH.

Carter, C. & Graham, R. (2000). Experimental comparison of manual and voice controls for the operation of in-vehicle systems. In Proceedings of the Human Factors and Ergonomics Society, 44th Annual Meeting. Human Factors Society, Santa Monica, CA.

Collins, P., Ball, A. & Maning, T. (1997). The application of direct voice input to battlefield helicopters. In Innovation in Rotorcraft Technology – Meeting. London: Royal Aeronautical Society.

Dixon, P. (1982). Plans and written directions for complex tasks. Journal of Verbal Learning and Verbal Behavior, 21, 70-84.

Dennison, T. W. (1987). The effect of simulated helicopter vibration on voice recognition system performance. In AHS, Annual Forum. 43rd, Saint Louis. MO.

Enterkin, P. (1991). Voice versus manual techniques for airborne data entry correction. In Proceedings of the Ergonomics Society Annual Conference, Ergonomics – Design for Performance. London: Taylor & Francis.

Hart, S. G. (1988). Helicopter human factors. In E. L. Wiener & D. C. Nagel (Eds.), Human Factors in Aviation (pp. 591-538). San Diego; Toronto: Academic Press.

Junqua, J. C. (1996). The influence of accoustics on speech production: A noise-induced stress phenomenon known as the Lombard reflex. Speech Communication, 20, 13-22.

Lee, J. D., Caven, B., Haake, S. & Brown, T. L. (2000). Speech-based interaction with in-vehicle computers: The effect of speech-based e-mail on drivers' attention to the roadway [On-line]. Available: www-nrd.nhtsa.dot.gov/driver-distraction/Welcome.htm

Loftus, G. R. & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. Psychonomic Bulletin & Review, 1, 476-490.

Swail, C. & Kobiersky, R. (1997). Direct voice input for control of an avionics management system. In American Helicopter Society Avionics and Crew Systems Technical Specialists' Meeting. Philadelphia.

Wickens, C. D. (1984). Engineering Psychology and Human Performance. Columbus, OH: Charles Merrill.

Appendix A**Information Mail-Out Sent to Participants****Experiment to Evaluate a Prototype****Direct Voice Input Operator Interface****For the CH 146 Griffon**

The purpose of this project is to develop and evaluate an operationally suitable Direct Voice Input (DVI) Operator Interface (OI) for the CH 146 Griffon helicopter. This OI must complement the Canadian Marconi Company (CMC) Control Display Unit, which serves as the databus controller for the Griffon helicopter. The effort will further the work done in conjunction with both a CMC/Department of National Defence (DND) project to demonstrate research technology onboard a National Research Council (NRC) Bell 412 helicopter and DVI research conducted at the Civil Institute of Environmental Medicine (DCIEM) using a CMC developed experimental test environment.

The Canadian Forces (CF) Utility Transport Helicopter (UTTH) is a modern Land Aviation aircraft that is used in numerous complex roles. The core of the CH 146 avionics management system architecture is a CMC Control and Display Unit (CDU). The location and method of operation of the CDU requires extended head-down operation by the pilot in some circumstances, which has been found to have flight safety implications in the tactical helicopter environment, particularly in bad weather or when using Night Vision Goggles (NVGs).

As part of this project, a command vocabulary and structure (syntax) have been developed to allow interaction with the CDU. Each DVI command has the following

structure: <action><target><parameter>. Essentially, you are telling the CDU <what to do><to what> and <the data required to complete the task>. As an example, one of the implemented commands is “Set (action) Radio 1 (target) 127.5 (parameter).” In the DVI system, some functionality that goes beyond the current capabilities of the CDU has been introduced. One such feature that you may notice is the ability to refer to waypoints and radio presets by meaningful names, e.g. “Ottawa Airport” or “Fredericton Tower.”

The commands that form the basis of the experiment are attached to allow you to familiarize yourself with the language and structure of the DVI syntax.

There are two components to the DVI interface. The first, described above, is the syntax or language used to issue commands. The second, equally important, is the feedback provided to the user. Feedback is required to inform the user as to what was heard by the speech recognition system and the resulting changes in the aircraft systems. Several approaches to feedback were considered, but given the high auditory and visual workload in the Griffon, the feedback method selected for this experiment was an alerting tone indicating success or failure accompanied by a small, text-based display used to present more detailed information. A brief description of the display used to provide feedback during this study is presented in Figure 1. A sample dialog between the pilot and the DVI system, including the displayed feedback, is presented in Figure 2.

Figure 1: Description of Visual Feedback for Experiment

DVI Commands issued by the left-seat pilot:

“Computer”

QUERY BEEP

“Set Radio 1 137.5”

SUCCESS BEEP

“Monitor all radios”

SUCCESS BEEP

“Switch to Radio 5”

SUCCESS BEEP

Figure 2: Dialog between Left Seat Pilot and DVI System (Page 1 of 4)

"Set Radio 1 29.5"

ERROR BEEP

SET RADIO1 29.5
SWITCH TO RADIO5
!INVALID FREQUENCY!
OOO●

"Set Radio 1 129.5"

SUCCESS BEEP

SET RADIO1 129.5
SET RADIO1 29.5
OOO●

"Calculate ETA"

QUERY BEEP

CALCULATE ETA
SET RADIO1 137.5
?FROM WP?
OOO●

"Waypoint 9"

QUERY BEEP

SWITCH TO RADIO5
WP 9
?TO WAYPOINT?
OOO●

Figure 2: Dialog between Left Seat Pilot and DVI System (Page 2 of 4)

“Waypoint 16”

QUERY BEEP

CALCULATE ETA

WP 16

?GROUNDSPEED?

OOO●

....

“75 knots”

QUERY BEEP

CALCULATE ETA

GS 75

?START TIME?

OOO●

....

“Now”

QUERY BEEP

CALCULATE ETA

13:42:07

?FLT PLN OR DIRECT?

OOO●

....

“Flight Plan”

SUCCESS BEEP

CALCULATE ETA

FLT PLN

ETA 14:06:31

OOO●

....

Figure 2: Dialog between Left Seat Pilot and DVI System (Page 3 of 4)

“Standby”

STANDBY BEEP

CALULATE ETA

FLT PLN

ETA 14:06:31

OOO●

....

“Computer”

QUERY BEEP

CALULATE ETA

FLT PLN

ETA 14:06:31

OOO●

....

“Set Long Range Source to Doppler”

SUCCESS BEEP

SET LRN SOURCE DOP

CALCULATE ETA

ETA 14:06:31

OOO●

....

“Standby”

STANDBY BEEP

SET LRN SOURCE DOP

CALCULATE ETA

ETA 14:06:31

OOO●

....

Figure 2: Dialog between Left Seat Pilot and DVI System (Page 4 of 4)

The experiment you will be participating in will be conducted in the Aircraft Crewstation Demonstrator (ACD) at CMC in Kanata over a two-day period. The ACD is a moderate fidelity prototyping facility, similar to an aircraft simulator, which will be configured as a CH 146 Griffon. You will have the opportunity to become familiar with the ACD flight environment before any data is collected. In addition to learning about the ACD flight environment, you will be given training on the speech recognition equipment, the DVI syntax, and a prototype Cockpit Resource Management (CRM) model suggested by the introduction of DVI to a crew concept aircraft.

Over the course of the two days, you will be asked to act as both the flying and non-flying pilot during missions with the existing CDU and the DVI equipped cockpit. You will fly scenarios based on low level recce missions, performing typical flight tasks such as communicating with ground agencies, filing SITREPS, etc. During some missions, you will be asked to perform an additional visual and auditory target discrimination task. After the data collection is complete, you will be asked to complete an attitude questionnaire to collect your opinions on and experiences with the existing CDU and the DVI equipped cockpit.

Action	Target	Parameter
Set	VOR	VOR Frequency
Set	VOR	VOR Waypoint Number
Set	VOR	VOR ICAO Identifier
Set	ILS	ILS Frequency
Set	ILS	ILS Waypoint Number
Set	ILS	ILS ICAO Identifier
Set	HIS Mode	ADF
Set	HIS Mode	DF
Set	HIS Mode	Long Range
Set	HIS Mode	Short Range
Set	HIS Mode	Enroute
Set	HIS Mode	Terminal
Set	HIS Mode	Approach
Set	LRN Source	GPS
Set	LRN Source	GPS Revert
Set	LRN Source	Doppler
Set	DME	Normal
Set	DME	Hold
Set	DME	Standby
Set	Doppler Update	Manual
Set	Doppler Update	Automatic
Set	Header	Civil
Set	Header	Tactical
Set	Header	Comm
Set	Header	Nav
Set	Radio 1	V/UHF Frequency (Manual)
Set	Radio 1	Preset Number (Comm List)
Set	Radio 1	Channel Number (HVQK)
Set	Radio 1	AM
Set	Radio 1	FM
Set	Radio 2	V/UHF Frequency (Manual)
Set	Radio 2	Preset Number (Comm List)
Set	Radio 2	Channel Number (HVQK)
Set	Radio 2	AM
Set	Radio 2	FM
Set	Radio 3	V/UHF Frequency (Manual)
Set	Radio 3	Preset Number (Comm List)
Set	Radio 3	Channel Number (HVQK)
Set	Radio 5	HF Frequency (Manual)
Set	Radio 5	Preset Number (Comm List)
Set	ADF	ADF Frequency
Set	AFCS	SAS Mode
Set	AFCS	Attitude Mode
Set	Flight Director	Heading Hold

Action	Target	Parameter
Set	Flight Director	Nav
Set	Flight Director	ILS
Set	Flight Director	Back Course
Set	Flight Director	VOR
Set	Flight Director	Standby
Set	Flight Director	Altitude Hold
Set	Flight Director	Airspeed Hold
Set	Flight Director	Vertical Speed Hold
Set	HIS Course	(Course Number)
Set	HIS Heading	(Heading Number)
Set	Flight Plan Sequence	Auto
Set	Flight Plan Sequence	Manual
Squawk	N/A	(IFF Code)
Squawk	N/A	Ident
Activate	Flight Plan	Next
Activate	Fight Plan	Previous
Activate	Present Position Direct	Waipoint Number
Activate	Present Position Direct	Waypoint Name
Calculate	ETA	From Waypoint
Calculate	ETA	To Waypoint
Calculate	ETA	Start Time
Calculate	ETA	Groundspeed
Calculate	ETA	Route (Flight Plan / Direct)
Calculate	Fuel Requirements	From Waypoint
Calculate	Fuel Requirements	To Waypoint
Calculate	Fuel Requirements	Fuel Quantity
Calculate	Fuel Requirements	Fuel Flow
Calculate	Fuel Requirements	Route (Flight Plan / Direct)
Calculate	Bearing and Range	To Waypoint
Calculate	Bearing and Range	From Waypoint
Calculate	Duration and Range	Fuel Quantity
Calculate	Duration and Range	Fuel Flow
Calculate	Duration and Range	Groundspeed
Calculate	Required Groundspeed	From Waypoint
Calculate	Required Groundspeed	To Waypoint
Calculate	Required Groundspeed	Start Time
Calculate	Required Groundspeed	Time on Target
Calculate	Required Groundspeed	Route (Flight Plan / Direct)
Display	Radio 1 (i.e. Settings)	
Display	Radio 2	
Display	Radio 3	
Display	Radio 5	
Display	Quick Review	Flight Plan
Display	Quick Review	Waypoints

Action	Target	Parameter
Display	Quick Review	Storepoints
Display	Quick Review	Mobile
Display	Quick Review	Message
Display	Quick Review	Comm
Display	Quick Review	V/UHF 1 (or Radio)
Display	Quick Review	V/UHF 2
Display	Quick Review	UHF
Display	Quick Review	HF
Display	Data	Waypoint Number
Display	Data	Waypoint Name
Display	Data	Preset Number
Display	Data	Preset Name
Display	Data	HVQK Channel Number
Display	Nav (Navigation)	
Display	Navaid	
Display	Doppler	
Display	GPS	
Display	Flight Plan	
Display	Present Position	
Display	Message (Msg Waypoint)	
Display	Status	
Switch To	N/A	Radio 1
Switch To	N/A	Radio 2
Switch To	N/A	Radio 3
Switch To	N/A	Radio 4
Switch To	N/A	Radio 5
Switch To	N/A	ICS
Switch To	N/A	Private
Monitor	N/A	Radio 1
Monitor	N/A	Radio 2
Monitor	N/A	Radio 3
Monitor	N/A	Radio 4
Monitor	N/A	Radio 5
Monitor	N/A	Nav A
Monitor	N/A	Nav B
Monitor	N/A	All Radios
Monitor	N/A	All Nav
Stop Monitoring	N/A	Radio 1
Stop Monitoring	N/A	Radio 2
Stop Monitoring	N/A	Radio 3
Stop Monitoring	N/A	Radio 4
Stop Monitoring	N/A	Radio 5
Stop Monitoring	N/A	Nav A
Stop Monitoring	N/A	Nav B

Action	Target	Parameter
Stop Monitoring	N/A	All Radios
Stop Monitoring	N/A	All Nav
Isolate Me To	N/A	Radio 1
Isolate Me To	N/A	Radio 2
Isolate Me To	N/A	Radio 3
Isolate Me To	N/A	Radio 4
Isolate Me To	N/A	Radio 5
Isolate Me To	N/A	Nav A
Isolate Me To	N/A	Nav B

Appendix B

Background Information Form**Background Information**

This information helps us determine whether we have spoken to a broad sample of flight crews. To get an unbiased understanding of the concerns of the operation community, we must get feedback from a good cross-section of experience levels and backgrounds.

1. Age: _____ 2. Years in CF: _____
3. (Estimated) Total Flight Hours _____ 4. (Estimated) Total Griffon Hours _____
5. Are you ____ left or ____ right handed?
- 6a. Have you ever used speech recognition software or hardware before participating in this experiment?
_____ Yes _____ No
- 6b. If yes, please briefly describe the system, e.g. name of software package, and its application, e.g. dictation for word processing.

Appendix C

Informed Consent Form

CONSENT FORM

STUDY: Direct Voice Input vs. Manual Control in the CH 146 Griffon

FACULTY SPONSOR: Chris M. Herdman, Ph.D., Department of Psychology
Carleton University, Tel. (613)520-2600 x 8122

The purpose of this informed consent form is to ensure that you understand both the purpose of the study and the nature of your participation in it. The informed consent must provide you with enough information such that you have the opportunity to determine whether you wish to participate in the study. Please ask the researcher to clarify any concerns that you may have after reading this form.

Research Personnel

The following people are involved in this research project and may be contacted at any time should you require further information about this study:

<i>Faculty Sponsor:</i>	Dr. Chris M. Herdman (613-520-2600 x 8122)
<i>Principal Investigator:</i>	Lynda Lessard (613-520-2600 x 2696)
<i>Project Engineer:</i>	M. Gamble, Canadian Marconi Company (613-592-7400 x 2236)
<i>Scientific Authority:</i>	Dr. P. Farrell, Defence and Civil Institute of Environmental Medicine (416-635-2169)

Should you have any ethical concerns regarding this study, you may contact one for the following individuals:

Kimberly Matheson, Ph.D.	Chair, Psychology Department (613-520-2600 x 2648)
Mary Gick, Ph.D.	Chair, Ethics Committee (613-520-2600 x 2664)

Purpose

The purpose of the study is to assess mission effectiveness and flight safety using the existing CH 146 Griffon manual CDU interface compared to a Direct Voice Input (DVI) interface.

Task Requirements

In this study, you will be required to act as both the flying and non-flying pilots during mission-based scenarios in the Aircraft Crewstation Demonstrator (ACD). You will be asked to perform flight tasks such as changing radios, calculating fuel requirements, and following orders from a tasking agency using the CDU and a DVI interface under varying noise conditions. You will also be required to perform a target discrimination task for both audio and visual targets. After each interface type, you will be asked to complete questionnaires regarding your experiences.

Duration and Locale

The experimental session will last approximately 2 days. Approximately 8.5 hours over the two days will be spent in the cockpit, alternating between flying and non-flying duties. The remainder of the time will be spent learning to use the speech recognition system and completing questionnaires. The testing will take place at Canadian Marconi Company in Kanata, ON.

Potential Risks and Discomfort

Flying is a high-workload task. To minimize ongoing demands the duration of each flying session has been limited to 45 minutes. Please note that we are not evaluating your flying skills; we are simply interested in assessing your relative performance using manual input vs. DVI.

The principle risk of the experiment is a feeling of motion sickness, including nausea and headache. There is also a risk of eye fatigue, such as that associated with viewing a video display. Participation in this study, or indeed in any research, may involve risks that are currently unforeseen.

Anonymity and Confidentiality

All data collected in this experiment will be kept strictly confidential through the assignment of a coded identification number. The information provided will be used for research purposes only and you will not be identified by name in any research reports produced from this study. Further, the information provided is made available only to the researchers associated with this experiment.

Right to Withdraw/Omit

You will be permitted to not answer any question(s) that you choose to omit. Participation in this study is entirely voluntary and you may decide to stop participating at any time without any consequences to your career.

Declaration

I have read the above description of the study examining DVI in the CH 146 Griffon; I understand the conditions of my participation.

I understand that the principle risk of the experiment is a feeling of motion sickness, including nausea and headache. There is also a risk of eye fatigue, such as that associated with viewing a video display. In the highly unlikely event that I become injured during my participation, I agree to go with the experimenter to obtain medical treatment. Finally, I acknowledge that my participation in this study, or indeed in any research, may involve risks that are currently unforeseen. I understand and accept these risks.

I am aware that my vision and balance may be temporarily affected by any virtual reality experience, and I agree not to drive or operate dangerous machinery for a period of one hour. If I experience side effects from this virtual reality experience, I will return and report this to the experimenter. If, in the unlikely event that I become incapacitated during my participation, I hereby consent to whatever medical intervention that is required.

My signature indicates that I hereby consent to participate in this experiment.

Name of Participant

Name of Witness

Signature of Participant

Signature of Witness

Date

Date

Appendix D

Debriefing Form

Debriefing

The purpose of this research is to compare the existing manually controlled CH 146 Griffon cockpit configuration versus a proposed Direct Voice Input (DVI) equipped cockpit. It is hypothesized that the introduction of DVI will improve mission effectiveness and flight safety in the Griffon. In this experiment, heads-up/heads-down time will be used as an indicator of flight safety while task completion time, mission completion time, and subjective assessments of workload will be use as indicators of mission effectiveness.

The current location and method of operation of the CH 146 CDU requires extended head-down operation by the pilot in some circumstances, which has been found to have flight safety implications in the tactical helicopter environment, particularly in bad weather or when using Night Vision Goggles (NVGs).

One technology that may address this issue is DVI. DVI has the potential to reduce the amount of time that the pilot has to direct visual attention to controls and displays in the cockpit. In high workload applications where the crew's attention must be directed outside the cockpit, DVI has the potential to not only improve mission effectiveness, but also to improve operational mission safety margins.

In addition to measuring "heads-down" time, the target detection task was designed to evaluate possible competing visual and auditory demands associated with each system. The introduction of DVI into the Griffon cockpit may introduce auditory conflicts; however, this must be balanced against the visual conflicts that exist with the current CDU. Therefore, care must be taken to evaluate the strengths and weaknesses associated with each system.

If DVI is demonstrated to increase flight safety and/or mission effectiveness through increased heads-up time, further research will be conducted with the aim of implementing a fully-functional DVI system in the CH 146 Griffon.

We would like to thank you for your participation in this research. Your time and effort are greatly appreciated!

If you have any questions or comments about this research, please feel free to contact any of the following individuals:

Lynda Lessard	Researcher, Psychology Department, Carleton University	613-520-2600 x2696
Dr. C.M. Herdman	Faculty Advisor, Psychology Department, Carleton University	613-520-2600 x8122
Murray G. Gamble	Project Engineer, Canadian Marconi Company	613-592-7400 x2236
Dr. P. Farrell	Scientific Authority, Defence and Civil Institute of Environmental Medicine	416-635-2169

Should you have any ethical concerns regarding this study, you may contact:

Kimberly Matheson, Ph.D.	Chair of the Psychology Department	613-520-2600 x 2648
Mary Gick, Ph.D.	Chair of the Ethics Committee	613-520-2600 x 2664

Appendix E

Mission Scenario

Mission Scenario (Tasking Information)

- **Unit: 403**
- **Mission Number: AS165R**
- **No. Helos: 1**
- **Nature of Task: Route Recce/Stby for CSAR**
- **Est. Duration: 0.5 h**
- **C/S and Freq:**
 - Squadron C/S: “Zero” – 119.1**
 - Airborne Command and Communication: C/S “Magic” – 120.7**
- **Combat Intelligence Update: Magic is coordinating agency. There has been significant nighttime activity with little activity during the day. Focus of recce missions is to determine the extent of the damage during these nighttime raids.**
- **Remarks: Fast air hard deck at 300’ AGL, all helicopters to remain 200’ AGL and below. Rotary wing airspeed restriction of 60 KIAS for co-ordination control. Mandatory reporting crossing phase lines to all coordinating agencies.**

Appendix F

Map using the Military Grid Reference System

Appendix G

Workload Questionnaire

Workload Section

Workload is the effort required to perform a task (operator load). Please rate the various mission segments of the experiment according to your perception of the demands made upon you. Rate each demand independent of your previous answers. All are rated from "Low = 0" to "High = 10". Please circle your response rating.

Name	Description	Mission Segment	Ratings from Low "0" to High "10"										
Visual Demand	Effort needed to gather all visual information required for each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10
Auditory Demand	Effort needed to gather all auditory information required for each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10
Mental Demand	Thinking and perceptual effort required for each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10
Physical Demand	Physical activity required for each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10

Name	Description	Mission Segment	Ratings from Low "0" to High "10"										
Time Pressure	Degree of time pressure felt for each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10
Your Own Performance	Success at accomplishing the tasks of each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10
Effort	Overall level of effort, both physically and mentally, during each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10
Frustration	Level of frustration during each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10
Anxiety	Level of anxiety during each mission segment.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10

Name	Description	Mission Segment	Ratings from Low "0" to High "10"										
Global Workload	Considering all aspects, how would you rate the demands of the current mission segments.	Transit and Recce	0	1	2	3	4	5	6	7	8	9	10
		Retasking	0	1	2	3	4	5	6	7	8	9	10
		Contact detection, Observation, and Report	0	1	2	3	4	5	6	7	8	9	10

Appendix H

Description of Mission Segments

Description of Mission Segments

Flight Planning Stage

- Crew is seated at a desk and given a maximum of 10 minutes to plan their flight. They are provided with flight plan information (including NAV data, timings, and features to be Recce'd) a map, ruler and marker. NFP plans the mission route with the FP observing.

Before Start Up

- Pilots are then seated in the dimly lit cockpit. The visual scene is running
- The crew, controlling agencies, and the experimental observer put on headsets and the pilots adjust their seats if necessary.
- Ambient helicopter noise is turned on.
- A sound check is performed, followed by head-up and head-down head calibration for both pilots.
- Pilots are then told that they have a maximum of 2 minutes before take off, and can now start to enter flight data.

Mission Segment #1 – Start Up to Take Off

- Experimental data is now being collected
- Crew enters flight plan and communications information, and NFP verifies flight route while still remaining on the ground.
- When ready, crew requests take off from 'zero'.
- Once take off clearance is given, the crew commences take off.

Mission Segment #2 – Take Off to Start Recce#1

- Aircraft touches off the ground and departs Home, flying directly towards the first waypoint.
- Crew is instructed throughout the mission to maintain an airspeed of 60 knots, and an altitude of 200 feet.
- Crew informs both 'zero' and 'magic' of status (i.e. just departed home plate, and heading towards 1st waypoint).

Mission Segment #3 – Start Recce #1 to Complete Recce #1

- Recce begins once crew has arrived at 1st waypoint. They now commence looking for contacts along the designated feature (i.e. river, road, or coastline).
- NFP verifies time, turn heading, and track angle departure at each waypoint in order to insure maintenance of the correct route.
- Crew informs both 'zero' and 'magic' that they have commenced the first leg of the recce.
- As part of the Airspace Coordination Effort the crew informs both 'zero' and 'magic' when they have crossed phase line apple.
- When contact is spotted the NFP advises 'magic' and gathers the relevant information (magic - contact wait out). 'Magic' tells the crew to switch to an alternate magic frequency to submit the contact report.
- Crew either hovers near the contact or flies slowly by in order to gain the necessary information. Once they have all the information they submit their contact report to 'magic' using the SALUTE method (Size, Activity, Location, Unit, Time, and other).
- 'Magic' then informs the crew that a ground unit has the situation under control, and that they are to proceed on route. They, therefore, proceed to their next waypoint following the feature, scanning for more contacts.

- Status report is given to 'zero' (delayed due to contact, but back on route).
- Either before, or shortly after arriving at the end of the first leg the crew is informed by 'magic' that they have been retasked, and that the second leg of their recce has changed.
- Crew loiter at the end of the 1st leg, until they check the new route and make sure everything looks right, reading back the route to 'magic' means accepting the route.

Mission Segment #4 – Complete Recce #1 to Start Recce #2

- Once they have accepted the new route they proceed directly to the 1st waypoint of the 2nd leg. During this time the NFP is entering the new flight plan information, and 'zero' is given a status report.

Mission Segment #5 – Start Recce #2 to Complete Recce #2

- Recce begins once crew has arrived at first waypoint of the second leg. They now commence looking for contacts along the designated feature (i.e. river, road, or coastline).
- Crew informs both 'zero' and 'magic' that they have commenced the second leg of the recce.
- Crew informs both 'zero' and 'magic' when they have crossed phase line apple.
- When contact is spotted the NFP advises 'magic' (contact wait out). 'Magic' tells the crew to switch to an alternate magic frequency to submit the contact report.
- Crew either hovers near the contact or flies slowly by in order to gain the necessary information. Once they have all necessary information they submit their contact report to 'magic' using the SALUTE method (Size, Activity, Location, Unit, Time, and other).
- 'Magic' informs the crew that a ground unit has the situation under control, and that they are to proceed on route. They, therefore, proceed to their next waypoint following the feature, scanning for more contacts.
- Status report is given to 'zero' (delayed due to contact, but back on route).
- At some point during the recce the crew is asked by 'magic' to squawk ident, which means to activate a switch, which allows the aircraft to be identified on radar.
- Crew proceeds to the end of the second leg, and request further instructions from 'magic'. 'Magic' informs them to proceed directly home.

Mission Segment #6 – Complete Recce #2 to Landing

- While transiting home, the crew is requested by 'magic' to switch to an alternate 'magic' frequency. Once switched 'magic' requests the crew to calculate their endurance and range, as they may be required for a CSAR mission.
- The crew calculates the endurance and range and advises 'magic'. A few moments later the crew is informed that they are not required for the CSAR, and should proceed to their home base.
- Upon approaching home, the crew requests landing clearance from 'zero', and land once cleared.

Appendix I

ANOVA Tables and Tables of Means and Standard Deviations - Experiment 1Percent Head-Up Time

Table 1

ANOVA Table of Mean Percent Head-Up Time (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Role	109,525	1	109,525.8	62.03**
Error	17,657	10	(1,765.8)	
Input	15,239	1	15,239.4	20.88**
Error	7,299	10	(729.9)	
Segment	68,067	5	13,613.6	108.08**
Error	6,297	50	(126.3)	
Role x input	6,396	1	6,396.5	8.20*
Error	7,803	10	(780.4)	
Role x segment	8,166	5	1,633.4	12.75**
Error	6,403	50	(128.1)	
Input x segment	4,139	5	827.9	8.00**
Error	5,172	50	(103.5)	
Role x input x segment	4,355	5	871.1	11.01**
Error	3,954	50	(79.1)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 2

Means and Standard Deviations of Percent Head-Up Time (CRM Uncontrolled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	32.9	13.5	11.4	12.3
	2	99.9	0.2	54.1	23.2
	3	99.5	1.0	51.8	18.4
	4	99.5	1.5	21.8	20.6
	5	99.6	1.0	49.2	20.3
	6	99.7	0.5	39.3	21.6
DVI	1	65.0	20.9	35.9	24.8
	2	99.8	0.4	64.1	30.2
	3	99.8	0.4	69.3	27.9
	4	99.6	1.3	51.5	26.3
	5	99.4	1.4	73.0	23.0
	6	99.6	0.7	83.9	24.3

Table 3

ANOVA Table of Mean Percent Head-Up Time (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Role	97,981	1	97,981.3	47.73**
Error	18,474	9	(2,053.0)	
Input	11,823	1	11,823.6	15.12**
Error	7,036	9	(781.8)	
Segment	62,157	5	12,431.5	96.69**
Error	5,785	45	(128.6)	
Role x input	5,280	1	5,280.4	6.27*
Error	7,574	9	(841.6)	
Role x segment	6,644	5	1,329.0	11.07**
Error	5,401	45	(120.0)	
Input x segment	3,511	5	702.3	5.88**
Error	5,378	45	(119.5)	
Role x input x segment	3,137	5	627.5	7.09**
Error	3,981	45	(88.5)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 4

Means and Standard Deviations of Percent Head-Up Time (CRM Controlled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	33.5	14.1	11.5	13.0
	2	99.9	0.2	52.7	26.2
	3	99.5	1.2	51.3	18.8
	4	99.4	1.8	26.3	24.8
	5	99.5	1.1	50.1	21.7
	6	99.6	0.6	40.8	23.6
DVI	1	61.4	19.7	36.3	26.1
	2	99.8	0.4	60.0	30.5
	3	99.7	0.5	68.2	29.1
	4	99.5	1.4	53.9	27.2
	5	99.3	1.5	71.8	23.1
	6	99.6	0.7	83.1	25.4

Percent CDU Time

Table 5

ANOVA Table of Percent CDU Time (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Role	2,5722	1	25,722.5	31.62**
Error	8,134	10	(813.4)	
Input	10,513	1	10,513.1	26.41**
Error	3,981	10	(398.1)	
Segment	49,019	5	9,803.9	92.03**
Error	5,326	50	(106.5)	
Role x input	3,751	1	3,751.8	12.11**
Error	3,099	10	(309.9)	
Role x segment	2,661	5	532.4	5.84**
Error	4,553	50	(91.1)	
Input x segment	4,589	5	917.9	7.68**
Error	5,978	50	(119.6)	
Role x input x segment	1,799	5	359.8	6.35**
Error	2,832	50	(56.6)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 6

Means and Standard Deviations of Percent CDU Time (CRM Uncontrolled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	55.0	18.2	67.4	14.9
	2	0.1	0.2	19.7	10.6
	3	0.3	0.8	23.8	8.2
	4	0.4	1.1	39.8	21.8
	5	0.4	1.0	25.5	14.0
	6	0.2	0.5	43.8	15.2
DVI	1	24.8	18.9	38.8	21.5
	2	0.0	0.1	6.1	13.6
	3	0.1	0.3	12.7	16.3
	4	0.4	1.2	19.7	24.5
	5	0.4	0.9	11.3	15.3
	6	0.1	0.5	10.6	20.1

Table 7

ANOVA Table of Percent CDU Time (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Role	22,071	1	22,070.8	24.34**
Error	8,160	9	(906.6)	
Input	7,741	1	7,741.2	18.30**
Error	3,807	9	(423.0)	
Segment	46,297	5	9,259.4	79.26**
Error	5,257	45	(116.8)	
Role x input	2,800	1	2,799.6	8.61*
Error	2,926	9	(325.1)	
Role x segment	1,965	5	393.1	3.92**
Error	4,513	45	(100.3)	
Input x segment	3,613	5	722.7	5.51**
Error	5,906	45	(131.2)	
Role x input x segment	1,087	5	217.3	3.14*
Error	3,110	45	(69.1)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 8

Means and Standard Deviations of Percent CDU Time (CRM Controlled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	53.7	18.6	67.6	15.7
	2	0.0	0.0	19.7	12.8
	3	0.3	1.1	23.3	8.9
	4	0.4	1.3	36.5	25.0
	5	0.4	1.1	23.5	14.9
	6	0.2	0.5	40.7	15.8
DVI	1	26.8	18.7	40.0	22.2
	2	0.0	0.1	6.3	13.8
	3	0.2	0.3	12.7	18.2
	4	0.4	1.3	20.0	24.2
	5	0.5	1.0	11.6	15.5
	6	0.1	0.4	11.4	21.0

Percent Map/Instruments Time

Table 9

ANOVA Table of Percent Map/Instruments Time (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Role	27,827	1	27,827.0	48.87**
Error	5,694	10	(569.4)	
Input	390	1	389.8	3.24
Error	1,204	10	(120.4)	
Segment	4,087	5	817.5	7.50**
Error	5,450	50	(109.0)	
Role x input	308	1	308.0	1.63
Error	1,892	10	(189.2)	
Role x segment	3,752	5	750.5	6.49**
Error	5,782	50	(115.6)	
Input x segment	541	5	108.2	1.37
Error	3,951	50	(79.0)	
Role x input x segment	722	5	144.4	3.34*
Error	2,163	50	(43.3)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 10

Means and Standard Deviations of Percent Map/Instruments Time (CRM Uncontrolled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	12.1	7.6	21.2	11.1
	2	0.1	0.1	26.2	15.5
	3	0.2	0.3	24.5	12.1
	4	0.1	0.4	34.7	22.6
	5	0.1	0.1	25.3	12.7
	6	0.1	0.1	16.8	13.0
DVI	1	10.3	11.1	25.3	13.7
	2	0.2	0.4	29.8	23.5
	3	0.1	0.2	16.1	16.5
	4	0.1	0.1	28.8	21.9
	5	0.2	0.5	15.7	10.9
	6	0.2	0.6	5.5	5.0

Table 11

ANOVA Table of Percent Map/Instruments Time (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Role	26,816	1	26,816.7	40.216**
Error	6,001	9	(666.8)	
Input	494	1	494.0	3.911
Error	1,137	9	(126.3)	
Segment	3,428	5	685.5	5.776**
Error	5,341	45	(118.7)	
Role x input	334	1	334.3	1.797
Error	1,675	9	(786.1)	
Role x segment	4,031	5	806.1	6.943**
Error	5,225	45	(116.1)	
Input x segment	759	5	151.8	1.726
Error	3,957	45	(87.9)	
Role x input x segment	811	5	162.2	4.309**
Error	1,694	45	(37.6)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 12

Means and Standard Deviations of Percent Map/Instruments Time (CRM Controlled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	12.8	7.6	20.9	11.6
	2	0.1	0.2	27.6	17.4
	3	0.2	0.3	25.4	12.3
	4	0.1	0.5	37.2	25.8
	5	1.8	5.4	26.5	14.2
	6	0.1	0.1	18.4	13.5
DVI	1	11.2	11.3	23.7	13.4
	2	0.2	0.4	33.8	24.3
	3	0.1	0.2	19.0	17.0
	4	0.1	0.2	26.1	20.3
	5	0.2	0.5	16.6	10.9
	6	0.3	0.7	5.5	5.2

Subjective Workload Results

Table 13

ANOVA Table of Mean Workload Ratings

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Role	2	1	2.2	0.16
Error	149	11	(13.5)	
Input	18	1	17.7	0.93
Error	210	11	(19.1)	
Workload type	165	8	20.6	5.22**
Error	35	88	(3.9)	
Role x input	33	1	32.6	5.55*
Error	7	11	(5.9)	
Role x workload type	34	8	4.2	3.36**
Error	111	88	(1.3)	
Input x workload type	16	8	2.0	1.21
Error	144	88	(1.6)	
Role x input x workload type	7	8	0.9	0.97
Error	77	88	(0.9)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 14

Means and Standard Deviations of Workload Ratings

Workload type	Flying pilots				Non-flying pilots			
	Manual		DVI		Manual		DVI	
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Visual	5.7	2.1	4.3	2.2	5.7	1.9	4.2	1.7
Auditory	4.3	1.6	4.6	2.2	5.4	1.9	4.7	2.4
Mental	4.8	2.1	5.0	2.6	5.5	1.4	4.9	2.3
Physical	4.3	2.1	4.5	2.8	3.8	1.2	2.9	1.8
Time pressure	3.3	2.2	3.8	2.2	5.3	1.5	4.0	2.0
Effort	4.8	2.2	5.4	2.7	5.7	1.8	5.1	1.9
Frustration	3.7	1.7	3.9	2.3	4.1	2.4	3.6	2.5
Anxiety	3.4	1.7	3.8	3.7	3.9	2.1	2.9	1.8
Global workload	4.8	2.0	5.2	2.5	5.8	1.9	4.6	1.9

Appendix J

ANOVA Tables and Tables of Means and Standard Deviations - Experiment 2Percent Head-Up Time

Table 1

ANOVA Table of Mean Percent Head-Up Time (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	7,356	1	7,356.4	28.81**
Input x role	3,209	1	3,209.5	12.57**
Error	2,042	8	(255.3)	
Segment	12,983	5	2,596.7	15.56**
Segment x role	7,386	5	1,477.4	8.85**
Error	6,675	40	(166.9)	
Input x segment	1,025	5	205.2	2.45
Input x segment x role	1,133	5	226.7	2.70*
Error	3,352	40	(83.8)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 2

Means and Standard Deviations of Percent Head-Up Time (CRM Uncontrolled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	75.1	17.7	18.8	7.9
	2	85.2	25.6	54.9	15.1
	3	93.9	12.0	54.9	16.3
	4	99.5	1.2	25.7	16.9
	5	98.5	2.3	53.6	22.6
	6	97.1	4.4	47.4	21.4
DVI	1	89.1	9.2	41.8	16.3
	2	97.4	5.8	79.6	14.2
	3	99.0	1.9	79.6	9.5
	4	98.9	2.6	37.8	20.5
	5	98.1	3.9	77.9	7.2
	6	98.7	2.6	94.6	4.0

Table 3

ANOVA Table of Mean Percent Head-Up Time (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	6,384	1	6,383.9	24.18**
Input x role	2,643	1	2,643.2	10.01*
Error	2,112	8	(264.1)	
Segment	13,273	5	2,654.7	15.07**
Segment x role	7,559	5	1,511.8	8.58**
Error	7,044	40	(176.1)	
Input x segment	1,309	5	261.7	3.34*
Input x segment x role	1,211	5	242.2	3.09*
Error	3,133	40	(78.3)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 4

Means and Standard Deviations of Percent Head-Up Time (CRM Controlled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	75.1	17.7	18.8	7.9
	2	86.1	23.7	57.6	16.7
	3	93.7	12.4	54.3	15.4
	4	99.7	0.7	29.2	20.4
	5	98.4	2.5	55.9	23.2
	6	96.9	4.7	48.9	22.4
DVI	1	89.1	9.2	41.7	16.2
	2	97.4	5.8	79.5	14.3
	3	99.0	2.0	79.0	10.1
	4	98.9	2.6	35.3	19.8
	5	98.2	3.7	78.0	7.1
	6	98.7	2.6	95.0	3.8

Percent CDU Time

Table 5

ANOVA Table of Percent CDU Time (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	4,458	1	4,457.6	56.60**
Input x role	3,274	1	3,273.9	41.57**
Error	630	8	(78.8)	
Segment	9,463	5	1,892.5	25.66**
Segment x role	2,204	5	440.8	5.98**
Error	2,951	40	(73.8)	
Input x segment	881	5	176.2	3.14*
Input x segment x role	664	5	132.8	2.37
Error	2,244	40	(56.1)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 6

Means and Standard Deviations of Percent CDU Time (CRM Uncontrolled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	18.4	13.4	65.8	13.7
	2	0.0	0.0	18.3	11.7
	3	0.0	0.0	28.7	8.3
	4	0.0	0.0	36.8	14.2
	5	0.2	0.5	26.2	11.4
	6	0.2	0.4	41.6	12.4
DVI	1	8.1	7.4	39.2	16.4
	2	0.0	0.0	9.4	10.7
	3	0.1	0.2	9.5	7.9
	4	0.0	0.0	17.3	16.7
	5	0.1	0.3	4.7	5.1
	6	0.0	0.0	1.5	1.9

Table 7

ANOVA Table of Mean Percent CDU Time (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	3,607	1	3,606.8	40.42**
Input x role	2,551	1	2,550.5	28.58**
Error	714	8	(89.2)	
Segment	9,979	5	1,995.8	26.26**
Segment x role	2,395	5	479.0	6.30**
Error	3,040	40	(76.0)	
Input x segment	1,114	5	222.8	4.35**
Input x segment x role	771	5	154.1	3.01*
Error	2,051	40	(51.3)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 8

Means and Standard Deviations of Percent CDU Time (CRM Controlled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	18.4	13.4	65.8	13.7
	2	0.0	0.0	14.2	11.1
	3	0.0	0.0	29.4	7.2
	4	0.0	0.0	30.3	15.5
	5	0.2	0.5	22.9	11.3
	6	0.2	0.4	40.1	13.6
DVI	1	8.1	7.4	39.2	16.4
	2	0.0	0.0	9.5	10.7
	3	0.1	0.2	9.7	8.2
	4	0.0	0.0	16.9	16.5
	5	0.1	0.3	4.7	5.2
	6	0.0	0.0	1.6	1.9

Percent Map/Instruments Time

Table 9

ANOVA Table of Mean Percent Map/Instruments Time (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	361	1	361.2	2.06
Input x role	0	1	0.3	0.00
Error	1,402	8	(175.2)	
Segment	3,043	5	608.6	4.68**
Segment x role	3,930	5	786.0	6.04**
Error	5,205	40	(130.1)	
Input x segment	942	5	188.4	2.64*
Input x segment x role	189	5	37.8	0.53
Error	2,854	40	(71.4)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 10

Means and Standard Deviations of Percent Map/Instruments Time (CRM Uncontrolled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	6.5	5.0	15.5	12.2
	2	14.8	25.6	26.7	16.5
	3	6.1	11.9	16.4	9.1
	4	0.5	1.2	37.5	22.8
	5	1.3	2.3	20.2	11.9
	6	2.7	4.1	11.0	11.0
DVI	1	2.9	2.1	19.0	3.3
	2	2.6	5.8	11.0	10.8
	3	0.9	1.9	10.9	6.7
	4	1.1	2.6	44.8	22.6
	5	1.7	3.9	17.5	9.3
	6	1.3	2.6	3.9	2.7

Table 11

ANOVA Table of Mean Percent Map/Instruments Time (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	395	1	394.6	2.39
Input x role	1	1	0.9	0.01
Error	1,322	8	(165.2)	
Segment	3,613	5	722.5	5.47**
Segment x role	4,680	5	935.9	7.08**
Error	5,285	40	(132.1)	
Input x segment	956	5	191.5	3.10*
Input x segment x role	223	5	44.6	0.72
Error	2,470	40	(61.7)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 12

Means and Standard Deviations of Percent Map/Instruments Time (CRM Controlled)

Input type	Segment	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	1	6.5	5.1	15.5	12.2
	2	13.9	23.7	28.2	16.7
	3	6.3	12.3	16.3	9.5
	4	0.3	0.7	40.5	22.1
	5	1.4	2.5	21.1	13.1
	6	2.9	4.3	11.0	11.2
DVI	1	2.9	2.1	19.0	3.3
	2	2.6	5.8	11.1	10.8
	3	0.9	2.1	11.3	7.0
	4	1.2	2.6	47.8	23.1
	5	1.7	3.7	17.3	9.5
	6	1.3	2.6	3.5	3.0

Latency Results

Table 13

ANOVA Table of Mean Reaction Time Medians (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Between-subjects effect				
Role	739,630	1	739,630.1	16.49**
Error	403,786	9	(44,865.2)	
Within-subjects effects				
Input	6,117	1	6,116.8	0.47
Input x role	112,890	1	112,889.6	8.74*
Error	116,280	9	(12,919.9)	
Target	461,566	1	461,565.7	7.93*
Target x role	31,800	1	31,799.8	0.55
Error	523,851	9	(58,205.7)	
Condition	2,204,174	1	2,204,174.2	96.47**
Condition x role	48,132	1	48,132.3	2.11
Error	205,645	9	(22,849.5)	
Input x target	5,879	1	5,878.7	0.68
Input x target x role	9,677	1	9,677.3	1.11
Error	78,183	9	(8,687.0)	
Input x condition	12,674	1	12,674.4	1.59
Input x condition x role	42,476	1	42,476.3	5.32*
Error	71,928	9	(7,992.0)	
Target x condition	55,968	1	55,968.3	4.45
Target x condition x role	20,466	1	20,465.9	1.63
Error	113,325	9	12,591.7	
Input x target x condition	12,348	1	12,347.9	2.93
Input x target x condition x role	1,742	1	1,742.0	0.41
Error	37,899	9	4,211.0	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 14

Means and Standard Deviations of Median Reaction Times (CRM Uncontrolled)

Input type	Target	Condition	Flying pilots		Non-flying pilots	
			<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	Visual	Baseline	415.2	33.8	575.6	126.4
		Dual	569.3	111.1	955.3	127.2
	Auditory	Baseline	512.8	136.3	682.3	145.1
		Dual	764.0	133.4	1,072.3	271.4
DVI	Visual	Baseline	430.9	42.1	560.0	102.2
		Dual	656.0	108.6	869.8	85.3
	Auditory	Baseline	538.0	102.6	627.7	116.8
		Dual	991.1	257.2	1,007.3	199.7

Table 15

ANOVA Table of Mean Reaction Time Medians (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Between-subjects effect				
Role	731,817	1	731,817.5	16.83**
Error	391,345	9	(43,482.7)	
Within-subjects effects				
Input	4,829	1	4,829.0	0.35
Input x role	120,359	1	120,359.3	8.76*
Error	123,705	9	(13,745.0)	
Target	448,151	1	448,151.2	7.72*
Target x role	28,878	1	28,278.4	0.50
Error	522,479	9	(58,053.2)	
Condition	2,123,103	1	2,123,103.3	96.04**
Condition x role	46,155	1	46,154.7	2.09
Error	198,949	9	(22,105.4)	
Input x target	5,604	1	5,604.4	0.60
Input x target x role	8,660	1	8,660.1	0.92
Error	84,631	9	(9,403.5)	
Input x condition	10,787	1	10,787.2	1.27
Input x condition x role	47,105	1	47,104.5	5.55*
Error	76,370	9	(8,485.5)	
Target x condition	51,362	1	51,361.5	4.09
Target x condition x role	18,136	1	18,136.2	1.45
Error	112,931	9	(12,547.8)	
Input x target x condition	11,949	1	11,948.9	2.51
Input x target x condition x role	1,327	1	1,326.7	0.28
Error	42,861	9	(4,762.4)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 16

Means and Standard Deviations of Median Reaction Time (CRM Controlled)

Input type	Target	Condition	Flying pilots		Non-flying pilots	
			<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	Visual	Baseline	415.2	33.8	575.6	126.4
		Dual	566.3	105.5	953.7	127.9
	Auditory	Baseline	512.8	136.3	682.3	145.1
		Dual	756.2	132.7	1,068.6	274.0
DVI	Visual	Baseline	430.9	42.1	559.9	102.2
		Dual	657.0	109.2	858.3	86.5
	Auditory	Baseline	538.0	102.6	627.7	116.8
		Dual	981.2	259.0	996.7	197.0

Overall Mean Percent Correct Responses (Accuracy Results)

Table 17

ANOVA Table of Mean Percent Correct Responses (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Between-subjects effect				
Role	234	1	233.6	0.50
Error	4,204	9	(467.1)	
Within-subjects effects				
Input	380	1	380.0	8.00*
Input x role	2,640	1	2,639.5	55.56**
Error	428	9	(47.5)	
Target	626	1	626.5	14.35**
Target x role	2,343	1	2,343.3	53.66**
Error	393	9	(43.7)	
Condition	16,981	1	16,981.4	40.28**
Condition x role	91	1	91.4	0.22
Error	3,795	9	(421.6)	
Input x target	322	1	321.6	7.27*
Input x target x role	58	1	57.7	1.30
Error	398	9	(44.3)	
Input x condition	289	1	288.8	7.05*
Input x condition x role	2,389	1	2,388.8	58.33**
Error	369	9	(41.0)	
Target x condition	666	1	666.1	20.080**
Target x condition x role	2,269	1	2,268.6	68.39**
Error	299	9	(33.2)	
Input x target x condition	415	1	415.3	11.15*
Input x target x condition x role	27	1	26.5	0.71
Error	335	9	(37.2)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 18

Means and Standard Deviations of Mean Percent Correct Responses (CRM Uncontrolled)

Input Type	Target	Condition	Flying Pilots		Non-Flying Pilots	
			<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	Visual	Baseline	100.0	0.0	100.0	0.0
		Dual	85.6	15.0	46.1	17.2
	Auditory	Baseline	98.6	1.9	100.0	0.0
		Dual	81.4	17.2	88.5	11.3
DVI	Visual	Baseline	97.9	3.2	100.0	0.0
		Dual	61.8	27.5	70.7	11.1
	Auditory	Baseline	98.6	1.9	100.0	0.0
		Dual	46.6	21.8	91.2	9.0

Table 19

ANOVA Table of Mean Percent Correct Responses (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Between-subjects effect				
Role	181	1	181.1	0.40
Error	4,094	9	(454.9)	
Within-subjects effects				
Input	407	1	407.3	8.92*
Input x role	2,366	1	2,366.1	51.81**
Error	411	9	(45.7)	
Target	625	1	625.0	16.57**
Target x role	2,283	1	2,282.6	60.53**
Error	339	9	(37.7)	
Condition	16,304	1	16,304.4	39.54**
Condition x role	70	1	70.3	0.17
Error	3,711	9	(412.3)	
Input x target	320	1	319.5	7.54*
Input x target x role	36	1	36.3	0.86
Error	381	9	(42.4)	
Input x condition	290	1	290.1	6.75*
Input x condition x role	2,189	1	2,189.4	50.95**
Error	387	9	(43.0)	
Target x condition	698	1	698.4	22.40**
Target x condition x role	2,270	1	2,270.2	72.81**
Error	281	9	(31.2)	
Input x target x condition	387	1	387.0	11.07*
Input x target x condition x role	9	1	8.6	0.25
Error	315	9	(35.0)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 20

Means and Standard Deviations of Mean Percent Correct Responses (CRM Controlled)

Input type	Target	Condition	Flying pilots		Non-flying pilots	
			<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	Visual	Baseline	100.0	0.0	100.0	0.0
		Dual	85.5	14.6	47.4	17.3
	Auditory	Baseline	98.6	1.9	100.0	0.0
		Dual	82.2	15.8	88.8	11.1
DVI	Visual	Baseline	97.9	3.2	100.0	0.0
		Dual	63.2	27.1	69.8	10.8
	Auditory	Baseline	98.6	1.9	99.4	1.4
		Dual	47.7	22.1	91.3	8.9

Mean Percent Correct Responses by Head Position

Table 21

ANOVA Table of Mean Percent Correct Responses while Looking Up (CRMUncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Between-subjects effect				
Role	840	1	840.4	0.990
Error	7,638	9	(848.7)	
Within-subjects effects				
Input	1,011	1	1,011.1	15.144**
Input x role	4,448	1	4,448.4	66.630**
Error	601	9	(66.8)	
Target	522	1	522.4	8.421*
Target x role	3,389	1	3,389.5	54.644**
Error	558	9	(62.0)	
Input x target	449	1	448.9	11.232*
Input x target x role	18	1	18.3	0.459
Error	360	9	(40.0)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 22

Means and Standard Deviations of Mean Percent Correct Responses while Looking Up
(CRM Uncontrolled)

Input type	Target	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	Visual	86.7	16.2	56.4	9.9
	Auditory	81.1	18.0	88.6	11.6
DVI	Visual	62.0	27.7	74.7	8.5
	Auditory	46.2	21.5	91.5	8.6

Table 23

ANOVA Table of Mean Percent Correct Responses while Looking Up (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Between-subjects effect				
Role	733	1	733.1	0.89
Error	7,453	9	(828.1)	
Within-subjects effects				
Input	992	1	992.1	14.21**
Input x role	4,154	1	4,153.6	59.51**
Error	628	9	(69.8)	
Target	520	1	520.1	8.85*
Target x role	3,295	1	3,295.2	56.06**
Error	529	9	(58.8)	
Input x target	455	1	455.0	10.39*
Input x target x role	5	1	5.2	0.12
Error	394	9	(43.8)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 24

Means and Standard Deviations of Mean Percent Correct Responses while Looking Up**(CRM Controlled)**

Input type	Target	Flying pilots		Non-flying pilots	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>
Manual	Visual	86.8	15.9	57.4	10.5
	Auditory	82.1	16.5	88.8	11.6
DVI	Visual	63.5	27.3	74.5	9.3
	Auditory	47.2	21.8	91.6	8.5

Table 25

ANOVA Table of Mean Percent Correct Responses for NFPs while looking at CDUs**(CRM Uncontrolled)**

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	1,990	1	1,990.1	10.755*
Error	925	5	(185.0)	
Target	9,347	1	9,346.9	50.078**
Error	933	5	(186.6)	
Input x target	880	1	879.6	1.094
Error	4,019	5	(803.8)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 26

Means and Standard Deviations of Mean Percent Correct Responses for NFPs while looking at CDUs (CRM Uncontrolled)

Input type	Target	Non-flying pilots	
		<u>M</u>	<u>SD</u>
Manual	Visual	33.6	21.4
	Auditory	85.1	16.6
DVI	Visual	63.9	23.3
	Auditory	91.3	16.1

Table 27

ANOVA Table of Mean Percent Correct Responses for NFPs while looking at CDUs (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	1,896	1	1,896.0	10.372
Error	914	5	(182.8)	
Target	9,163	1	9,163.1	49.832**
Error	919	5	(183.9)	
Input x target	874	1	874.3	1.116
Error	3,918	5	(783.6)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 28

Means and Standard Deviations of Mean Percent Correct Responses for NFPs while looking at CDUs (CRM Controlled)

Input Type	Target	Non-Flying Pilots	
		<u>M</u>	<u>SD</u>
Manual	Visual	34.4	20.6
	Auditory	85.5	15.9
DVI	Visual	64.2	23.9
	Auditory	91.3	16.1

Table 29

ANOVA Table of Mean Percent Correct Responses for NFPs while looking at Map/Instruments (CRM Uncontrolled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	293	1	292.8	1.348
Error	1,086	5	(217.2)	
Target	5,122	1	5,122.3	13.293*
Error	1,927	5	(385.3)	
Input x target	376	1	375.7	0.885
Error	2,122	5	(424.4)	

Note. Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .01$.

Table 30

Means and Standard Deviations of Mean Percent Correct Responses for NFPs while looking at Map/Instruments (CRM Uncontrolled)

Input Type	Target	Non-Flying Pilots	
		<u>M</u>	<u>SD</u>
Manual	Visual	52.5	25.6
	Auditory	89.7	11.9
DVI	Visual	67.4	31.3
	Auditory	88.7	11.5

Table 31

ANOVA Table of Mean Percent Correct Responses for NFPs while looking at Map/Instruments (CRM Controlled)

Source	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Input	292	1	292.1	1.44
Error	1,014	5	(202.9)	
Target	5,253	1	5,252.6	14.21*
Error	1,849	5	(369.8)	
Input x target	346	1	345.5	0.83
Error	2,079	5	(415.9)	

Note. Values enclosed in parentheses represent mean square errors. * $p < .05$. ** $p < .01$.

Table 32

Means and Standard Deviations of Mean Percent Correct Responses while looking at Map/Instruments (CRM Controlled)

Input type	Target	Non-flying pilots	
		<u>M</u>	<u>SD</u>
Manual	Visual	52.2	25.0
	Auditory	89.3	12.4
DVI	Visual	66.7	31.4
	Auditory	88.7	11.5