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The Influence of ATC Message Length and Timing on Pilot Communication

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SUMMARY

Pilot-controller communication is critical to safe and efficient flight. It is often a challenging component of piloting, which is reflected in the number of incidents and accidents involving miscommunication. Our previous field study identified communication problems that disrupt routine communication between pilots and controllers. The present part-task simulation study followed up the field results with a more controlled investigation of communication problems. Pilots flew a simulation in which they were frequently vectored by Air Traffic Control (ATC), requiring intensive communication with the controller. While flying, pilots also performed a secondary visual monitoring task. We examined the influence of message length (one message with four commands vs. two messages with two commands each) and noncommunication workload on communication accuracy and length. Longer ATC messages appeared to overload pilot working memory, resulting in more incorrect or partial readbacks, as well as more requests to repeat the message. The timing between the two short messages also influenced communication. The second message interfered with memory for or response to the first short message when it was delivered too soon after the first message. Performing the secondary monitoring task did not influence communication. Instead, communication reduced monitoring accuracy.

INTRODUCTION

Pilot-controller communication is often challenging: controllers present complex messages with time-critical information over an often noisy, busy radio medium. Not surprisingly, this link between air and ground can be disrupted by a variety of problems. Partly in response to problems with the current radio system, several groups have proposed adding a data-link capability to air-ground communication (Kerns, 1990; Lee & Lozito, 1989). Any change to the current system should be based on a thorough understanding of communication strategies and problems in this system. A model of pilot-controller communication in the radio environment would help guide design and evaluation of changes to ATC communication messages, procedures, or medium. To provide constraints on such a model, we have conducted a field study investigating the organization of routine and nonroutine pilot-controller communication (Morrow, Lee, & Rodvold, in press; Morrow, Rodvold, & Lee, in press). The present paper describes a part-task simulation study that follows up some of the field results. Before describing the study, we outline an approach to controller-pilot communication that identifies important cognitive processes.

A. Routine Pilot-Controller Communication

As in other kinds of dialogue, pilots and controllers communicate by following a collaborative scheme (Clark & Schaefer, 1987; Morrow, Rodvold, & Lee, in press). Typically, controllers initiate a transaction with the intended aircraft's callsign and then present the message. They use particular speech acts to accomplish their goals. For example, they report information about airspace conditions (traffic, weather), command pilots to perform actions, and request information about flight conditions. After the message is received, both controller and pilot must accept it as mutually understood and appropriate--pilots acknowledge the message with their callsign and a readback of the commands, which the controller checks for accuracy. These collaborative functions involve (at least) the following cognitive processes.

A1. Controller presents message- **(a) Formulating:** According to plan-based approaches to language production, formulating a message involves first deciding which information to present--the message content (Levelt, 1989). Message formulation is often embedded in a larger plan to accomplish the overall task goal. ATC message formulation is part of developing and executing a sector plan, that is the controller's plan for moving aircraft through their sector (Human Technology, 1991). **(b) Packaging:** Next, controllers decide how much information to present in a single message and in what order to present it. This step also involves coding, or deciding which words and phrases will express the information. Packaging and formulating should be guided by schemes for ATC message organization. These schemes specify standard or conventional ATC terminology and phrases and the order for presenting the phrases in a message. It is also constrained by limited working memory capacity (Bock, 1982) and by the dynamics of the controller's task (e.g., how long the controller has to say the message).

(c) **Delivering:** Finally, controllers decide how rapidly to present the message, when to pause, etc. Delivery will also depend on time pressures related to controller workload.

A2. Pilot understands message- Pilots listen to messages in order to identify the intended addressee and the actions that the controller expects them to perform. Comprehension involves recognizing words, parsing phrases, and updating a mental model of the flight conditions. Comprehension is also constrained by working memory, particularly when concurrent tasks compete for limited processing resources (Wickens & Flach, 1988).

A3. Pilot and controller accept message- Accepting the message as mutually understood and appropriate often hinges on pilot readbacks. Pilots keep the message in working memory in order to read back the commands, and controllers keep the message in working memory in order to verify the readback. After the message is accepted, the controller continues with the next turn or begins a new transaction, and the pilot responds to the message by operating aircraft controls, telling the pilot flying to do so, or loading the information into the Flight Management System (FMS). Accepting and responding to the message may be concurrent.

B. Communication Problems

Routine collaboration can be disrupted by a variety of problems, producing nonroutine transactions in which acceptance is delayed because pilots and controllers must indicate and repair the problem (Morrow, Lee, & Rodvold, in press; Morrow, Rodvold, & Lee, in press). The following is a list of possible failures or breakdowns in collaboration.

B1. Initiation failure- The wrong pilot can respond to a message because of callsign confusion, forcing the controller to correct the addressee and repeat the message for the intended pilot (Monan, 1983). Pilots may also fail to hear the message, forcing the controller to repeat the message. Repeating unacknowledged messages was a frequent problem in our field study (Morrow, Rodvold, & Lee, in press).

B2. Understanding failure- Pilots may notice that a message is for them, but misunderstand all or part of the message. Misunderstanding can occur at different levels. First, pilots may fail to interpret all or part of the message, which they indicate by requesting a repeat of the message ("Say again heading"). Second, they may interpret the message, but be uncertain of their interpretation, which they indicate by requesting confirmation ("Was that heading 120?"). Finally, they may misunderstand the message but not realize it (a monitoring failure), which is signalled by an incorrect readback. All three kinds of failures occurred in the nonroutine transactions from our field study (Morrow, et al., in press).

B3. Memory failure- Pilots may understand a message but forget it before they respond. For example, cockpit duties or subsequent ATC or cockpit communication may interfere with memory for the message, particularly if the second event is similar to the message (Wickens, 1992). Memory failures may produce delayed problems where the pilot asks for clarification after the transaction is completed, which requires "reopening" the closed transaction.

B4. Information failure- Finally, a message may be understood and remembered, but the pilot disagrees with its accuracy, timing, or completeness. Information problems must also be resolved before final acceptance (Billings & Cheaney, 1981; Morrow, Rodvold, & Lee, in press).

C. Causes of Problems

The previous section suggests several causes of communication problems.

C1. Message factors- (a) **Poor formulation**: Problems may arise because incorrect or outdated information is presented in the first place (Billings & Cheaney, 1981). (b) **Poor packaging**: Controllers may present too much information in one message, or the message may be too complex. Both laboratory (Loftus, Dark, & Williams,1979) and field research (Billings & Cheaney, 1981; Morrow, Lee, & Rodvold, in press) show that longer ATC messages are harder to understand and remember. (c) **Poor delivery**: Controllers may present the message too rapidly, with poor enunciation or with misleading stress/intonation cues. These practices can also reduce pilot memory for messages (Monan, 1983). They may also present one message too quickly after a previous one, disrupting comprehension, memory, or response to the earlier message.

C2. Medium factors- Message factors can be compounded by noisy or overloaded radio frequencies (Billings & Cheaney, 1981).

*C3. Task factors: **Workload**-* The working memory demands from message and medium factors are more likely to lead to pilot communication problems when concurrent flight tasks compete for limited capacity.

D. Part-Task Study: Controller Presentation Strategies and Pilot Communication

The present study investigated the influence of ATC message length and timing, as well as noncommunication workload, on pilot communication during simulated flight. Controllers either presented one long message (with 4 commands) or divided the message into two short messages (with 2 commands each) with a variable intermessage interval (see Figure 1 for an example). The next section describes how message length and timing may influence communication.

D1. Controller presents one long message- Controllers may present long messages in order to save time. While they spend more time on formulating longer messages (unless the 4 commands are integral dimensions of a single planning unit such as a control action), they save packaging and delivery time because the number of turns is reduced. However, pilots are more likely to misunderstand long messages because of increased working memory load. With 4 commands presented at once, pilots are less likely to hear or interpret all or part of the message, resulting in more incorrect or partial readbacks and requests for clarification (Billings & Cheaney, 1981; Morrow, et al., in press). Long ATC messages may decrease communication efficiency as well as accuracy. Transactions with long rather than short ATC messages may be longer overall (containing more turns and speech acts) because more talk is needed to indicate and repair problems.

D2. Controller presents two short messages- Controllers may need more time to package and deliver two short messages, so they may try to save time by presenting the two messages in quick succession. Presenting shorter messages should reduce pilot misunderstanding by reducing working memory load (Morrow, Lee, & Rodvold, in press). However, presenting the second message too quickly after the first may interfere with remembering and/or responding to the earlier message. Therefore, pilots may indicate a problem with the first message after the second short message has occurred. These delayed problems are more likely for short intervals between the first and second short message. To sum up, short, closely spaced messages should produce memory failures while long messages produce understanding failures. Nonetheless, problems should still be less frequent for short than for long ATC messages. Transaction length may increase for short ATC messages because the controller uses more turns. Transactions will only be longer when they contain long ATC messages if the talk required to clarify communication problems (which are more frequent after long messages) outweighs increases in length due to additional turns in the short message condition.

D3. Workload and communication medium- We also examined if performing a secondary monitoring task interfered with the pilot's ability to communicate with the controller. During half of the flights, pilots monitored a visual display that was similar to a flight instrument display. In addition, a parallel study examined if ATC message length influenced data-link as well as radio communication (McGann, Lozito, & Corker, 1992). Because data-link provides a more permanent visual communication medium, long messages are less likely to overload pilot working memory and create communication problems. Researchers have proposed that the data-link medium is more appropriate than the voice medium for long, complex ATC messages. However, rapidly presented messages could cause problems in both radio and data-link media (Kerns, 1990).

Long Message Transaction (One Controller Message With Four Commands)

Controller Turn:

NASA Seven One Four, turn left heading three six zero
climb and maintain one one thousand
maintain two five zero knots
contact Oakland Center on one two seven point niner five

Pilot Acknowledgment and Readback

Short Message Transaction (Long Message is Divided into Two Short Messages with Two Commands Each)

Controller Turn 1:

NASA Seven One Four, turn left heading three six zero
climb and maintain one one thousand

Pilot Acknowledgment and Readback 1

[Variable time delay here between pilot readback and second controller message: 1-108 seconds; the majority of intervals were less than 10 seconds]

Controller Turn 2:

maintain two five zero knots
contact Oakland Center on one two seven point niner five

Pilot Acknowledgment and Readback 2

Figure 1. Examples of Long and Short Message Transactions in the Part Task Study

METHODS

A. Subjects

Sixteen male aircraft pilots (mean age = 38.7 years) with substantial experience in "glass cockpits" in air transport operations participated in the study. Twelve subjects were first officers and four were captains.

B. Equipment

The simulation consisted of a network of three computers: (a) Silicon Graphics workstation simulating an ATC radar station equiped with a Bay TRACON (Terminal Radar Control Facility) data-base. (b) Silicon Graphics workstation simulating a glass cockpit flight deck display (Figure 2). Thrust was controlled by a mouse and pitch and yaw were controlled by a joystick. (c) Macintosh computer that presented the pre-recorded ATC messages. It also presented the secondary monitoring task (Figure 3 presents the visual monitoring task display). These computers were networked so that the controller could track the subject's aircraft on the radar screen, control delivery of the pre-recorded voice ATC messages over the Macintosh, and send data-link messages to the flight deck display. The controller and pilot were also connected by a telephone-radio system so that they could talk to each other during the flights.

Flight data were recorded once every five seconds (once per second during communication) and integrated into data files with message acknowledgment times and monitoring task data.

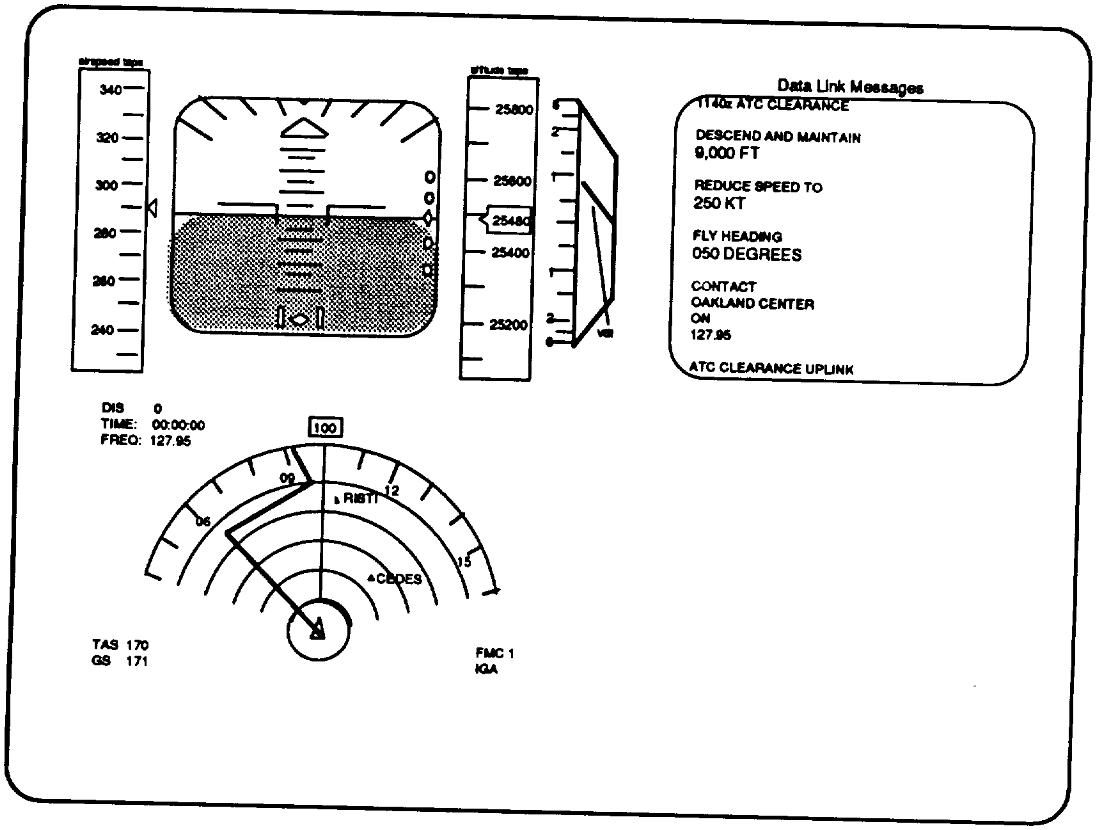

Figure 2. Flight Deck Display

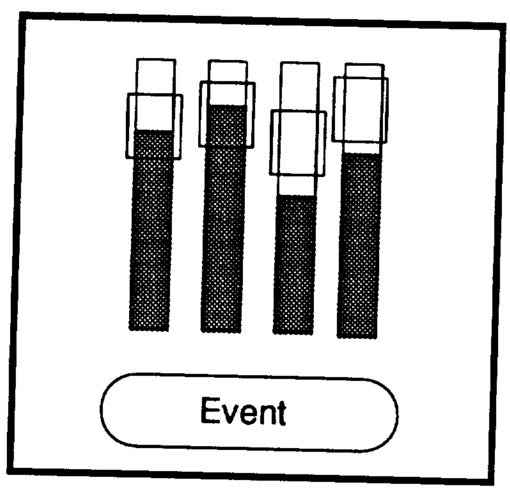

Figure 3. Secondary Monitoring Task

C. Design

The present study examined message length and workload in a radio/voice environment along with a parallel study that examined message length in a data-link environment (see McGann, et al., 1992 for more detail). Across these two studies, ATC message length (long, first short, second short) and Secondary task load (flying with and without monitoring task), and Communication medium (radio and data-link) were varied within subjects, with length and medium crossed. Secondary task load was varied only within the radio condition. Radio and data-link legs were blocked with order of blocks counterbalanced across subjects. In the radio/voice condition, the order of legs with and without the secondary task was varied, and in data-link, the order of display formats was varied.

We investigated the impact of these factors on the following measures. (a) **Verbal communication:** frequency and type of problems indicating that the pilot did not understand or remember ATC messages; transaction length (number of turns and speech acts). (b) **Communication response time:** time for pilots to initiate message acknowledgment after the offset of the radio message; time to initiate heading changes and to enter radio frequencies (altitude and speed times could not be reliably determined). (c) **Secondary task performance**. Target response accuracy (percent of hits) and detection time was measured for the secondary task.

D. Flight Scenario and Procedure

Each subject flew four legs between San Francisco and Sacramento airports while being vectored by ATC. The flight began at about 500 feet on Departure and ended on final with a hand-off from Approach to Tower. Within each flight phase (departure, center, and approach), long and short message conditions alternated, with a long (4 command) message followed by a pair of short (2 command) messages, or vice versa. There were 18 messages per leg: 6 long and 6 pairs of short messages. All messages were written and delivered by a retired TRACON controller. In the radio condition, the messages were recorded by the same controller, digitized and stored on the Macintosh computer. This controller and a second controller also participated in the experiment. During the flight, the controllers handled delivery of the messages from their workstation keyboard. They also responded to pilot requests for clarification by resending the full message via the keyboard, by verbally repeating part of the message, or by answering questions.

In the radio condition, pilots were instructed to acknowledge each message by pushing a button next to the joystick (analogous to keying the microphone). Next, they were instructed to read back all commands in each message, but they could respond to the commands during or after the message and readback. In the data-link condition, subjects were informed of the arrival of data-link messages (presented in one of two formats on a display to the right of the primary flight display) by a chime. After reading the message, they hit a button to accept or reject the message and then responded to the commands (the simulation did not include an FMS or a mode control panel).

Subjects also performed a secondary task during half of the radio flights and during all data-link flights. They monitored a display on the Macintosh to the left of the flight display (within the visual field of the pilot). The display contained 4 columns that randomly fluctuated in height, and each column had a box that moved randomly and independently of the column (see Figure 3). Subjects pressed a button when 2 or more of the 4 columns entered their respective boxes (the target event). The display reset after approximately 4 seconds if the pilot did not respond. Monitoring accuracy and time were recorded by the computer. Subjects were instructed to give first priority to flying, then to communicating, and then to monitoring.

Before flying the 4 legs, each pilot participated in a 30-40 minute practice session. They practiced the monitoring task, then familiarized themselves with the simulator by flying vectors given by the controller over the radio for 5-10 minutes, and then they flew 5-10 minutes with vectors given over data link. Finally, they flew one more longer practice flight while performing the secondary task. Messages during this last practice flight were delivered by voice or data-link, depending on the subject's first experimental condition. After flying the first two experimental legs, pilots had another 10 minute practice session with the upcoming condition plus the secondary task.

RESULTS

A. Voice Communication

A1. Coding and analysis- **(a) Coding scheme:** Communication problems were coded based on a scheme from the earlier field study (Morrow, et al., , in press). Each transaction was coded for type of ATC message (Long, First Short, Second Short), type of communication problem, topic of problem, type of repair, and length of transaction (number of controller and pilot turns and speech acts, with the number of problem turns and speech acts separately identified). Table 1 presents the problem and repair types.

(b) Reliability: Two raters independently coded the voice communication from one leg (27 transactions, 70 turns, 167 speech acts). The lowest rate of agreement across coding categories was 89%.

(c) Analysis: First, the frequency of problems after long messages was compared to the sum of the problem frequencies after the two short messages, which allowed us to examine the influence of message length while holding constant the amount and type of message information. Procedural deviations, readback errors, and requests for clarification were separately analyzed by an ANOVA with message type as a repeated measure.

Second, specific types of understanding and memory problems after long, first short, and second short messages were analyzed: Requests for repeat of the message, which indicated that pilots did not hear or understand all or part of the message; Requests for confirmation, which indicated that they interpreted the message but were uncertain of their interpretation; and Incorrect readbacks, which indicated that they incorrectly interpreted the message. These frequencies were analyzed by a Message type by Problem type repeated measures ANOVA. Third, types of problems after the first short message were examined in greater detail. These analyses provide a profile of communication problems after different controller presentation strategies.

Finally, the impact of ATC message type on overall transaction length was examined in order to test if different presentation strategies influence communication efficiency as well as accuracy.

A2. Message length and communication accuracy- **(a) Frequency of problems after Long and Short Messages:** Performing the secondary monitoring task did not influence voice communication, so subsequent analyses collapsed over this variable. Table 2 presents the frequency of readback errors, requests for clarification, and procedural deviations after long ATC messages and after both short messages combined. Pilots made more readback errors after long messages than after both short messages ($F(1,15) = 7.1$, $p < .05$). They also asked for clarification more often after the long messages ($F(1,15) = 13.1$, $p < .01$), indicating that they did not understand the message and had to interrupt routine communication in order to clarify communication. They also made more procedural deviations (**F**(1,15)= 13,2, **p** < .01). They may have read back fewer commands after the long messages in order to reduce the workload imposed by these messages. To summarize, pilots were more likely to misunderstand the controller when too much information was presented in one message.

(b) Types of understanding problems after Long and Short Messages: Table 3 presents the frequency of readback errors, requests for repeat, and requests for confirmation after long, first short, and second short ATC messages. A Message by Problem type interaction (**F**(4,60)= 7.5, **p** < .001) showed that ATC message length had a different impact on the three problems.

To analyze the interaction, we examined the influence of message types for each problem type. The Message factor was significant for all three problems (**p** < .001 for all **F**'s) and was analyzed by planned comparisons between message types. Readbacks errors were more frequent after long than after the first short message (**F**(1,15)= 21.2, **p** < .001), with no difference between the two short messages (**F**(1,15)= 3.2, **p** = .10). Requests for repeat were also more frequent after long than after the first short message (**F**(1,15)= 23.1 **p** < .001), with no difference between first and second short messages (**F**(1,15)= 1.6, **p** > .10). Requests for confirmation showed a different pattern. There was no difference in the frequency of these requests after long and first short messages (**F**(1,15)= 1.1 **p** > .10), but they were more frequent after first than second short messages (**F**(1,15)= 11.4, **p** < .01). In other words, pilots were likely to request repeats of long messages, and to request confirmation of their interpretation of both long and first short messages (see Table 3).

(c) Problems after First Short Messages: Most problems after short messages were delayed (84%): Pilots indicated the problem only after they had read back the second short message (only 12% of pilot requests after long messages were delayed until after a subsequent transaction). Several findings suggest that the timing between the two short messages influenced communication, with the second short message interfering with pilot memory for or response to the first message. First, pilots initially understood the first short message--all commands in delayed problems had been correctly read back after the first short message and before the second short message. Second, pilots had often forgot all or part of these messages by the time the second message had occurred--70% of the delayed problems were requests for repeat or were incorrect requests for confirmation. Third, 42% of the incorrect requests for confirmation had one or more incorrect digits imported from the second short message (intrusion errors). These findings suggest that pilots usually understood the first short message (in contrast to the long messages), but then tended to forget part of the information either because the second message created retroactive interference (suggested by the intrusion errors), or the second message delayed the pilot's response to the first message, which increased chances of forgetting the information (Loftus, et al., 1979).

If the timing of the second message is critical, interference should increase for shorter intervals between readback of the first message and presentation of the second message. While problems appeared to be more frequent for shorter intermessage intervals (34% delayed problems for intervals less than 5 sec; 22% problems for intervals greater than 5 sec), the reliability of this difference was difficult to test because the intermessage interval varied nonsystematically (from1 to 108 seconds) both within and between subjects. In a post-hoc analysis, we did a median split of interval length for each subject and compared the frequency of delayed problems for these long and short intervals. Problems were no more frequent for short than for long intervals (short: 27%, long: 29%).

A3. Message length and overall transaction length- We examined the impact of ATC message length on overall transaction length by comparing the number of turns and speech acts in transactions with Long ATC messages to the number of turns and speech acts in both short ATC message transactions combined. Controllers and pilots talked more when ATC messages were divided into two short messages. There were more short message than long message transactions (mean number of short transactions per flight=13.5, long transactions per flight = 6.7), creating more turns ($t(15)=8.0$, $p < .01$) and speech acts ($t(15)=3.9$, $p < .01$) for the combined short message condition than for the long condition. However, **problem** turns and speech acts were more frequent for long than short messages ($t(15)=5.2$, $p < .01$) and speech acts ($t(15) = 4.9$, $p < .01$). In other words, even though pilots and controllers talked more in order to resolve communication problems after long messages, the amount of routine communication increased with shorter messages because the number of turns increased. Therefore, the strategy of breaking long into short messages increased communication accuracy, but at the expense of communication length.

B. Communication Response Time

In addition to voice communication, we examined time to initiate acknowledgement of and response to ATC messages. Acknowledgment initiation times were analyzed by a repeated measures ANOVA with Message Length (Long/First Short/Second Short) and Secondary Task (communication with and without secondary task) as factors. Presence of the secondary task did not significantly influence acknowledgment time (With secondary task: 1.3 sec, Without: 1.6 sec, $F(1,15)=3.6$, $p = .08$). However, message length influenced acknowledgment time (First short: 1.01 sec, Second short: 1.6, Long: 1.7, $F(2,30)=7.5$, $p < .01$), with acknowledgment time more rapid for the first than the second short message ($F(1,15)=11.7$, $p < .01$) and no difference between the second short and the long messages ($F(1,15)=1.5$, $p > .10$). In other words, the first short message was acknowledged more quickly than either the second short or the long message. Because acknowledgment initiation times were rapid, these differences may not have operational consequences.

Time to initiate a response to heading commands was not influenced by Message Length (Long: 11.7 sec Short:11.6 sec, $F(1,15) < 1.0$) or the secondary task (With: 11.3 sec Without: 12.0 sec, $F(1,15) < 1.0$). However, pilots took longer to enter assigned radio frequencies into the computer after long messages (Long: 18.0 sec Short:11.9 sec, $F(1,15)=15.1$ $p < .001$), perhaps because clarification of these messages delayed entry. The secondary task did not influence time to enter the frequencies (With: 13.6 sec Without: 16.3 sec, $F(1,15)=1.1$, ns).

C. Secondary Task During or After Communication

Finally, we examined the influence of pilot-controller communication on the secondary monitoring task. Because pilots were instructed to give priority to the communication task, they should "give-up" the secondary task during communication. We analyzed secondary task target detection time and accuracy at 5 lags after ATC message offset: target occurs 1-10 sec after message, 10.5-20 sec, 20.5-30 sec., 30.5-40 sec, and 40.5-50 sec. With shorter lags, pilots are more likely to be reading back and clarifying message when the target appears, resulting in slower and less accurate target detection. While target detection <u>time</u> was not influenced by the lag variable ($F(4,36) < 1.0$), detection <u>accuracy</u> decreased for shorter lags (Lag1: .19 correct, Lag2: .27, Lag3: .39, Lag4: .40, Lag5: .58; Overall $F(4,60)=15.2$, $p < .001$; Linear trend: $F(1,15)=110.1$, $p < .001$). Because this analysis may be influenced by the fact that many more targets occurred for lag5 than the other lags, we also compared mean accuracy during lags1-4 with accuracy during lag5. Accuracy was greater during the longer lag (.58 vs. .31 $t(15)=7.8$, $p < .001$).

DISCUSSION

A. Summary

The present findings confirm and expand the earlier field study of controller-pilot communication. First, the study confirms the finding that long ATC messages tend to overload pilot memory and create problems that disrupt routine communication. The present study suggests that certain types of problems are more likely after long ATC messages. Requests to repeat the ATC message were particularly frequent, showing that pilots did not hear or did not understand all or part of the message. While shortening messages improved accuracy, it tended to lengthen communication, because the number of turns required to convey the same amount of information increased. However, most of this additional communication was routine. On the other hand, transactions with long ATC messages had more problem turns and speech acts than transactions with short messages. Therefore, accuracy improved at the expense of transaction length when controllers divided long messages into shorter ones. This may be a reasonable trade-off, considering the paramount importance of accuracy to flight safety.

The present study also found that the timing between messages influenced communication accuracy. Although short messages created fewer problems than long messages, most of these short message problems concerned the first short message, and were delayed until after the second short message. Secondary analyses revealed different kinds of problems for short and long messages with a different time course. Long messages overloaded pilot memory so that they were unable to understand all of the message. Nonetheless, these problems were immediately indicated and quickly repaired. Short messages were usually understood since they imposed fewer demands on pilot working memory. Delivery of the second ATC message, however, sometimes disrupted the process of remembering and/or carrying out the first message. Because of this interference, pilots tended to forget the command and had to request a repeat or confirmation after responding to the second message. Rapid initiation of acknowledgement to the first short message may reflect pilot perception of time pressure after the first message.

Additional analysis of data from our pilot-controller communication field study suggests that controllers rarely present several messages to the same pilot in quick succession. Depending on the TRACON, only 2-5% of transactions had a second controller turn that was presented within 5 seconds of the pilot readback of the first turn. Delayed communication problems rarely occurred in these multi-message transactions (only 2.2% of the transactions with more than one controller turn had delayed problems). On the other hand, pilots failed to read back 9.3-15.2% of the second messages in these transactions (depending on the TRACON) compared to 7-12% missing readback rates for the total set of transactions. Similarly, in the present study, missing readback rates were higher after the second short messages (4.7%) than after the long messages (1%). These results suggest that pilots are less likely to explicitly accept messages that are presented in rapid succession. (This difference could also be related to the fact that the second short message in this study usually contained frequency changes and requests to report leaving or attaining an altitude, while the first messages were usually heading and altitude change clearances which are more time critical).

There are several reasons to think that the timing between messages may become more of an issue in future ATC operations. First, controllers are more likely to present messages in quick succession if they heed our advice and break long messages (which constitute 5-20% of transactions in typical samples of ATC communication) into shorter installments. They will be tempted to present these shorter messages in quick succession because they will need to present this information in a short period of time. Second, the pressure to present messages in quick succession will only increase in the future as aircraft scheduling becomes tighter in busy terminal operations and ATC communication becomes more frequent.

Future research must examine more systematically the costs and benefits of different controller presentation strategies. For example, what is the optimal message length and timing in different operational conditions? How are these strategies influenced by problems related to frequency congestion?

B. Limitations

Several aspects of the present study limit the realism of the simulation and thus the generality of the findings. First, there were no background ATC messages, and the controller only worked the subject's aircraft. Therefore, the costs involved in turn-taking over the radio were underestimated. More realistic scenarios will provide a more sensitive examination of costs and benefits associated with different collaborative strategies. Second, the secondary task was not well integrated into the flight and communication tasks, so the impact of noncommunication workload on ATC communication was not tested. Finally, conclusions about the impact of message timing in this study are restricted by the limited simulation. Because single pilot rather than crew operations were examined, the same pilot had to both fly the aircraft and communicate with the controller. With a two-person crew, the pilot communicating would be better able to handle ATC messages in quick succession. Therefore, it is reasonable to assume that problems will occur less frequently in cockpits with more than one pilot and with memory aids such as altitude and heading bugs. Nonetheless, the primary findings converge with the earlier field results to broaden our understanding of controller-pilot communication and the problems that disrupt this process.

CONCLUSIONS

A. Constraints on Models of Controller-Pilot Communication

The present study suggests that message length and message timing influence different cognitive processes involved in controller-pilot communication. While long messages reduced comprehension or immediate memory for messages by overloading working memory, short messages presented in quick succession were more likely to cause forgetting, with the later message intruding into memory for the earlier message. These observations may help constrain computational models of ATC communication (e.g., Deutsch & Palmucci, 1992), and may help integrate these models with theories of speaker-addressee collaboration during conversation.

B. Relationships Between Radio and Data-Link Communication

In a parallel study, McGann et al. (1992) examined the impact of long and short messages delivered by data-link on pilot communication and flying performance. They found few voice communication problems. The long ATC messages delivered by data-link did not create more voice communication problems or delay acceptance compared to short messages, suggesting that data-link may be better suited than voice/radio for delivering long, complex ATC messages (Kerns, 1990). However, it is possible that reading errors will increase for longer messages, depending on the type of data-link format and interface. The few voice communication problems that did occur in the data-link condition appeared to be more frequent for first short messages, and like radio, these problems were delayed until after the second short message. Similarly, acceptance time was faster for first short messages than for either the long message or second short message--the same pattern as for radio acknowledgement time even though data link accept times are much longer than radio acknowledgment times. These findings suggest that message timing may be an issue for data-link as well as for radio communication.

C. Measuring ATC Communication Performance

The earlier field results (Morrow, Rodvold, & Lee, in press) and the results from the present study suggest that measures of collaboration (e.g., frequency and type of problem indication and repairs) may provide a more sensitive index of communication problems than communication errors (e.g., readback errors) or operational errors (e.g., loss of aircraft separation). Analysis of communication failure should provide an important window on cognitive processes involved in air-ground communication.

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Table 1. COMMUNICATION PROBLEM AND REPAIR TYPES

Communication Problems
- Incorrect readback
- Request for clarification
  - Request repeat of all or part of the message ("Say Again")
  - Request confirmation ("Was that Heading 120?")
- Procedural deviation (Incomplete readback; no readback)
- Request report (e.g., altitude) not provided by pilot
- Controller repair not acknowledged by pilot

Communication Repairs
- Repeats all or part of the message
- Answers question ("Affirmative", "Negative", "That's correct")
- Answers question and repeats the message

Table 2. PERCENT OF READBACK ERRORS, REQUESTS FOR CLARIFICATION, AND PROCEDURAL DEVIATIONS RELATED TO LONG AND BOTH SHORT ATC MESSAGES

Problem Type	Message Type Long	Short
Readback Error	18	8
Request Clarification	65	33
Procedural Deviation	60	35

Table 3. PERCENT OF READBACK ERRORS, REQUESTS FOR REPEAT, AND REQUESTS FOR CONFIRMATION RELATED TO LONG, FIRST SHORT, AND SECOND SHORT ATC MESSAGES

	Message Type		
Problem Type	Long	First Short	Second Short
Readback Error	18	3	5
Request Repeat	46	10	6
Request Confirmation	18	14	3

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13. ABSTRACT *(Maximum 200 words)*

Pilot-controller communication is critical to safe and efficient flight. It is often a challenging component of piloting, which is reflected in the number of incidents and accidents involving miscommunication. Our previous field study identified communication problems that disrupt routine communication between pilots and controllers. The present part-task simulation study followed up the field results with a more controlled investigation of communication problems. Pilots flew a simulation in which they were frequently vectored by Air Traffic Control (ATC), requiring intensive communication with the controller. While flying, pilots also performed a secondary visual monitoring task. We examined the influence of message length (one message with four commands vs. two messages with two commands each) and noncommunication workload on communication accuracy and length. Longer ATC messages appeared to overload pilot working memory, resulting in more incorrect or partial readbacks, as well as more requests to repeat the message. The timing between the two short messages also influenced communication. The second message interfered with memory for or response to the first short message when it was delivered too soon after the first message. Performing the secondary monitoring task did not influence communication. Instead, communication reduced monitoring accuracy.

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