Dissertations and Theses

Spring 2013

Comparison of Voice and Text ATC Communications in the Cockpit for ESL Pilots

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Comparison of Voice and Text ATC Communications in the Cockpit for ESL Pilots

by

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B. S. Embry-Riddle Aeronautical University, 2012

A Graduate Thesis Submitted to the

Department of Human Factors and Systems

in Partial Fulfillment of the Requirement for the Degree of

Masters of Science in Human Factors and Systems

Embry-Riddle Aeronautical University

Daytona Beach, Florida

Spring 2013

COMPARISON OF VOICE AND TEXT ATC COMMUNICATIONS

IN THE COCKPIT FOR ESL PILOTS

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Acknowledgements

Completing my thesis has been a difficult, challenging, and rewarding process that would not have been possible without a list of people to whom I would like to thank. First I wish to thank my thesis advisor, Dr. Kring, who put in numerous hours discussing, reading, revising, and contemplating the various aspects of this thesis. Above all I would like to thank Dr. Kring for his incredible support and encouragement in the face of doubt, frustration, and discouragement. His constant support and positive attitude made it possible for me to complete my thesis in a timely manner.

I would also like to thank other faculty members and friends who acted as mentors, guiding me through this difficult process. First, I would like to thank Dr. Bradshaw-Hoppock for the effort she put into my thesis and was always there to relieve stress with a joke or a coffee. I would also like to thank Professor Vaden and Daniela for all the brainstorming they did with me as well as the continuous push to “get it done.” I would also like to thank Dr. Shappell who pushed me to make my thesis of higher caliber.

Finally, I would like to thank my family, friends, and boyfriend. I would like to thank my family for their love and support; especially my parents, who taught me that with hard work and determination I can accomplish anything. I would like to thank my friends for their encouragement, for listening to my venting, and understanding me in a way that only fellow students can. Lastly, I would like to thank my boyfriend, Glenn, who kept me sane throughout this process and believed in me in when I doubted myself.

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Abstract

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Title: Comparison of Voice and Text ATC Communications in the Cockpit for ESL Pilots

Institution: Embry-Riddle Aeronautical University

Year: 2013

Throughout the course of any flight, pilots and air traffic control (ATC) are in constant radio communication regarding the position and route of the aircraft. Effective pilot-ATC communication helps to increase safety by increasing the situation awareness of both the pilot and controller. In the current pilot-ATC communication system, auditory messages are sent back and forth between the pilot and controller. The nature of these auditory messages makes them highly susceptible to memory and information processing limitations. This effect is magnified when dealing with pilots who have learned English as a second language (ESL) as people have more difficulty processing information in their second language (L2). The study examined the effect of using mixed modality or redundant (auditory and visual) ATC messages in the cockpit on ESL pilots. The study employed a 2 x 2 mixed design with primary language as a between-subjects factor (monolingual, English speaking pilots vs. ESL pilots) and message modality as a within-subjects factor (auditory only vs. auditory and visual). Forty pilots, 20 in each language condition, conducted enroute and approach flight maneuvers while responding to pre-recorded ATC messages taken from real ATC transmissions. Each pilot was exposed to 20 clearances, ten visual and ten mixed. The researchers recorded each pilot's readback and assessed the response time and accuracy of each transmission. Each response time and accuracy score were calculated into an average for each participant based on clearance type. The responses were also calculated into a composite score that determined an accuracy to speed ratio. The results of the study indicated that both groups performed significantly better in the mixed modality; however, the study did not reveal any significant group differences.

Introduction

Communication between pilots and air traffic control (ATC) is essential for safe and successful flight operations. Throughout the course of a flight, ATC sends pilots auditory messages with instructions regarding route, altitude, speed, and other factors. These directions are to help assure safe and successful flight. However, the rapid transmission of these messages can seem overwhelming to pilots, which in turn, can increase workload and complicate an already complex environment in the cockpit. These issues are a direct result of overloading a pilot's cognitive resources due to the limitations of information processing. Research has found that bilingual individuals experience more difficulty and require more effort when processing in their second language (L2). With a growing number of pilots with English as a second language (ESL), this increased processing could become a more prominent issue in the aviation community. This study examines the use of mixed modality/redundant (auditory and visual) messages to improve communications between ESL pilots and ATC. This study assesses student ESL pilots' ability to communicate with ATC when messages are transmitted both orally and visually. The researchers measured the accuracy of the readback of ESL pilots compared to the accuracy of readbacks of control group pilots who only speak English. Overall, the goal of the experiment was to determine if the use of mixed modality/redundant presentation ATC messages would be beneficial to ESL student pilots.

Pilot and ATC Communications

Current methods of communication. Communication is essential for smooth operations in any workplace. Communications is defined as "an act of collaboration between two or more people" (Morrow, 1994). In aviation, the primary function of pilot-ATC communications is to help pilots navigate via the safest route possible (Federal Aviation Administration, 2012a). ATC helps pilots fly safely by aiding them in their efforts to maintain a minimum separation, or a minimum distance, between them and other aircraft. Most pilots begin their training under visual flight rules, or VFR. With VFR, pilots must rely on their ability to see outside the aircraft cockpit to fly the aircraft (Federal Aviation Administration, 2012b). VFR flight training involves learning the basic rules of flight, including basic flight maneuvers, procedures, and regulations. This instructional period focuses on teaching the student how to fly the aircraft during optimal, high visibility conditions. In contrast, pilots with an instrument rating fly under instrument flight rules (IFR), which allows them to fly in adverse weather conditions with low visibility (Federal Aviation Administration, 2012b). The IFR instructional period focuses on the purpose of the various instruments and how to use them during flight. IFR pilots are able to fly in low visibility conditions because they rely on cockpit instruments, instead of sight, to help them navigate. Due to the lower level of visibility, IFR pilots are also more reliant on ATC for separation and information services and therefore, they receive more complex and detailed clearances from ATC.

In all controlled airspaces and airfields, the FAA requires pilots to be in contact with and receive instructions from ATC. A controlled airfield is an airport that has an ATC tower that directs planes to taxi and take off at various runways and a controlled airspace is one that ATC monitors. Passing through a controlled airspace requires a pilot to notify ATC of his or her position and follow the directions given by ATC. The current manner in which ATC and pilots communicate is via radio messages that are transmitted to the pilot's headset on specific frequencies that are assigned by ATC. This message transmission between the pilot and ATC is a four-step process that typically includes: ATC sends a message to the pilot (1), the pilot listens to the message (2), the pilot then repeats the message back to ATC (3), and finally, ATC either accepts or corrects the message (4) (Prinzo & Britton, 1993). The portion where the pilot reads back the message to ATC is known as the readback, while the portion of the process where ATC listens and corrects the message is known as hearback (Connell, 1996). This iterative four-step process is referred to as the "pilot/controller communication loop" (Airbus, n.d.). When ATC accepts that the readback matches the hearback, ATC closes the "communication loop" (Morrow, 1994) between the pilot and the controller, thus indicating successful communication. The communication is considered successful when the transmitted message is acknowledged and mutually understood by both the pilot and the controller. This is a continuous process that begins when the pilot requests to ramp out and taxi on the runway and ends when the aircraft reaches its final destination and is parked at the airport. Although a communication loop is typically initiated when ATC contacts the pilot to give him or her instructions; pilots can contact ATC with questions or requests. Often pilots will request to change their heading, altitude, or airspeed, and all such requests are monitored by ATC.

Message content. The majority of ATC-pilot communications consist of the pilot requesting information and ATC giving the pilot instructions. Before flight, information from ATC consists of weather information and takeoff instructions. During flight, most ATC clearances consist of a combination of five critical pieces of information, designated by the acronym CRAFT (VATUSA-Training Resource Center, 2012); CRAFT stands for Callsign, Route, Altitude, Frequency, and Transponder code.

Callsign. The first piece of important information is the airplane's callsign, which is a series of numbers and letters that ATC uses to identify which pilot is being addressed. It is important that pilots and ATC use the entire callsign to determine which pilot is communicating with ATC. The callsign is supposed to be stated by ATC before every transmission to a pilot and in turn, a pilot should respond with his or her callsign before reading back a message to ATC.

Route. The second piece of information is the route, which determines the pathway the pilot will take. The route information can consist of a compass heading, waypoints, or directional instructions such as indicating to the pilot to turn right or left. Pilots may request route changes for various reasons, such as to avoid bad weather or to save time by taking a more direct route to their destination.

Altitude. The next piece of information is altitude, which specifies at which flight level the pilot should be operating. Often, instead of clearing a pilot to a specific altitude, ATC will clear a pilot to fly either above or below a specified altitude. Altitudes are assigned to help pilots maintain a certain level of separation, as it is difficult for a pilot to see a plane that is above or below him or her.

Frequency. ATC will also indicate which frequency the pilot should use to communicate with ATC. A frequency is a four-digit number that corresponds to a radio channel on which the message will be communicated. When a pilot enters a new airspace he or she is transferred to the next set of controllers who monitor the new airspace and he or she is required to confirm with ATC on the new frequency. This is to help assure that the pilot is communicating on the proper frequency and that ATC is aware of who is in the airspace.

Transponder code. The final piece of information that is commonly transmitted is the transponder code. The transponder code is a four digit number, often referred to as a "squawk." Pilots set the transponder code to a specific value; this value is transmitted to ATC to notify them of an aircraft's position. This allows ATC to monitor a pilot's location within an airspace to help maintain separation between aircraft and monitor for altitude and route deviations.

According to the International Civil Aviation Organization (ICAO), in the readback the pilot is only required to report back route clearances, takeoff related instructions, runway instructions, altimeter settings, transponder codes, altitude instructions, and transition levels (Krivonos, 2007). Although it is not required to read back all information, it is recommended that the pilot read back all ATC instructions as these common directions allow ATC to safely monitor a pilot's position and stay in contact with the pilot throughout the duration of the flight.

Mechanisms for improving clarity. When conducting communications with ATC, a pilot must share a radio frequency with many other pilots in the area, which can cause radio congestion and confusion. In order to help reduce radio congestion, pilots and controllers attempt to make communication short and simple through standard phraseology. Standard pilot-ATC phraseology dictates certain methods and phrases that pilots and controllers should use to make communications simple and brief, and the terminology is designed to be easily recognized and understood in the aviation community (Airbus, n.d.). The Airman's Instructional Manual (AIM) (Federal Aviation Administration, 2012a) provides a description of standard phraseology including the pronunciation of letters as well as the proper way to state specific flight information such as altitude and heading. These directions are in place to help clarify communications in a congested environment.

In addition to standard phraseology, ATC constructs directions to pilots to help establish an operational context and increase the clarity of the message (Airbus, n.d.). ATC uses specific modifiers and markers in their transmissions to help provide clarity to their messages. ATC establishes the purpose of the message through a statement of intent, such as declaring a request or posing a question. ATC also establishes when they intend for the pilot to conform to the direction; often ATC uses words such as "immediately" to indicate that the action must be performed right away or to tell the pilot to expect certain things later in the flight. ATC also provides information as to what they want the pilot to do and how they want him or her to perform the intended action. ATC uses phrases like climb to XXX altitude or turn left toward XX heading to indicate what and how actions should be performed by the pilot. ATC also indicates at what point of a pilot's flight path they intend for the pilot to perform the intended functions. ATC uses phrases such as "before" (i.e., before reaching XXX altitude) or "at" a certain waypoint to help clarify. These directions are designed to help make messages more clear and understandable, as misinterpreting messages from ATC could have dangerous results.

Issues in Pilot-ATC Communication. Over 70% of the incidents reported to the NASA Aviation Safety Reporting System (ASRS) involve some sort of error with the transfer of information (Connell, 1995). Morrow, Lee, and Rodvold (1993) defined ATC-pilot communication issues as any disruption to normal communication in which standard procedures are not followed and/or the communicated information must be clarified. While restating information has been shown to significantly increase pilot recall (Burki-Cohen, 1995), when ATC provides clarification, they tie up the radio, preventing other pilots from requesting information and receiving directions. However, without these time consuming clarifications, pilots would be operating based on false information, which can have disastrous results.

A survey of ASRS data (Connell, 1995) indicated that approximately one third of incidents in general aviation are associated with communication difficulties. Another report by Prinzo (1996) studied pilot-ATC communications at three different facilities by listening to recordings of pilot-ATC communications. Prinzo examined 6,300 ATC "communication elements," or pieces of information transmitted by ATC, and found that 40% contained at least one error. Of the 5,900 pilot "communication elements," or pieces of information transmitted by pilots, 59% contained some sort of error. Most of these pilot-ATC communication errors occur during the cruising phase of flight (Connell, 1995) and occur during the readback or hearback portion of the communication process (Prinzo & Britton, 1993). In addition, these communication difficulties usually fall into one of three categories

The three categories of communication difficulties encompass a pilot's failure to follow a clearance, issues with communication equipment, and poor pilot radio technique. These broader categories encompass a number of errors. Grayson and Billings (1981) conducted a study that examined 5,402 incidents reported to the ASRS that involved communication issues. They further decomposed communication problems into ten generic problem categories: misinterpretation or phonetic similarity, transposition, content inaccuracies, incomplete content, ambiguous phraseology, untimely transmission, broken or incomplete phraseology, absent data, equipment failures, and monitoring problems. These categories relate to a number of problems for pilots and controllers.

Similarity. The first category, phonetic similarity, refers to similar sounding words or numbers which can cause pilots to incorrectly recall numerical data such as an altitude or heading. A common mistake with phonetic similarity is that pilots will respond to a similar sounding callsign (Cardosi, 1996). This can cause the pilot to make route changes for another flight, putting the pilot off course and causing pilot tracking problems for ATC.

Transposition. Transposition occurs when a pilot unintentionally transposes the numbers in a transmission (Grayson & Billings, 1981); this may involve reversing the order of values in a given piece of data such as a frequency or swapping values in two different pieces of data such as interchanging the numbers in a frequency and a transponder code (Cardosi, 1997).

Content inaccuracies. Content inaccuracies refer to the pilot accurately receiving ATC's transmission, but the transmission provided erroneous data, such as a heading that conflicts with separation maintenance, weather advisories, or similar types of information (Grayson & Billings, 1981). This category also includes problems with misinterpreting a message, and typically occurs when a pilot misinterprets a message from ATC.

Incomplete content. Incomplete content refers to the transmitter not giving enough information for the receiver to fully understand the problem. An example is when ATC tells a pilot to descend to an altitude without telling them the rate of descent or when to begin descending.

Ambiguous phraseology. Ambiguous phraseology refers to the pilot or controller using phrases that are confusing or can be misinterpreted. This often results when pilots and controllers do not use standard phraseology. Phraseology problems typically lead to issues with altitude deviations, runway issues, and airborne conflicts (Connell, 1995).

Untimely transmission. An untimely transmission refers to information being transmitted at an ineffective time. If a message is sent too early it may be forgotten due to distractions by other tasks; in contrast, if a message is sent too late it may no longer be pertinent.

Broken or incomplete phraseology. Broken or incomplete phraseology usually results from faulty equipment or poor radio frequency as it involves the distortion of the physical sound that is being transmitted.

Absent data. Absent data refers to the sender's failure to transmit a message. This could be due to a multitude of factors including distraction or poor radio technique (Grayson & Billings, 1981).

Equipment failure. Equipment failure refers to the loss of a message due to technology (Grayson & Billings, 1981). Equipment failure can involve when a transmission device breaks or slightly malfunctions. Equipment failure is in part what occurred during the Tenerife accident when both pilots simultaneously attempted to contact ATC and as a result blocked each other's transmissions, thus causing the data to never be transmitted.

Monitoring problems. The last category, monitoring problems, refers to a pilot or controller's failure to properly monitor the frequency resulting in missing a transmission or not receiving the full message.

Common causes of communication issues. The ten categories of issues explained above can be attributed to a number of factors. Connell (1995) analyzed all incident submissions to the ASRS that involved communication issues. Of the reports analyzed, 50% involved issues with the controller's communication technique, while 46% involved problems with the pilot's communications technique (not mutually exclusive), representing the two highest problem areas observed. One problem area is readback/hearback. Readback/hearback problems typically cause incidents involving "altitude deviations, airborne conflicts, less than standard separation, track or heading deviation, and runways transgression" (Connell, 1995). All of these incidents not only cause problems for both pilots and controllers, but they could also lead to catastrophic events.

Problems with the readback/hearback and phraseology can be linked to a multitude of factors that can cause problems with all pilot-ATC communications. For example, one common problem that occurs during pilot-ATC communications is that a pilot will mishear a callsign that is similar to his or her own callsign and receive a message as if it was intended for him or her (Cardosi, 1996). If this problem goes undetected, it can lead to major problems, such as route deviations or separation issues. It is very important that controllers read the entire callsign, as to not confuse pilots with similar sounding callsigns. In addition, it is important that pilots include their callsign at the beginning of the readback. A study by Cardosi (1993) indicated that only 58% of the pilots used their full callsign in their readback, while 27% gave no callsign at all in their readback. Lack of a callsign forces ATC to have to identify pilots by voice alone. When a pilot uses or responds to a callsign that is not his or her own, it causes a significant increase in workload for ATC as they must now make extra transmissions to correct the pilot who mistakenly responded, as well as address the pilot they intended to contact.

Another cause for callsign confusions is expectancy. Often, a pilot will respond to another pilot's callsign with content similar to what the pilot is expecting (Krivonos, 2007). Although it can cause confusion, expectancy may aid in communication, for example pilots often become accustomed to certain airports that give typical instructions (Cardosi, 1996). This familiarity allows pilots to quickly process and respond to these routine clearances, enabling pilots to make better decisions and anticipate clearances. Sometimes however, expectancy will cause pilots to hear a clearance given to another pilot and respond to it as if it were his or her own.

A common mistake, especially in unfamiliar airspace, is that pilots will mishear a frequency and switch to the wrong channel before confirming the new frequency with ATC (Cardosi, 1993). Although this error is not as critical as other types of errors, such as a deviation in altitude or heading, frequency errors represent the largest amount of readback errors. Ironically, despite the common confusions in frequency, frequency is not one of the elements that pilots are required to read back (Airbus, n.d.). One common issue that often underlies frequency readback errors is the use of non-standard phraseology or jargon (Krivonos, 2007). For example, the Airman's manual states that ATC will relay a frequency to a pilot using a specific format that involves reading each individual number as opposed to the number as a whole (Federal Aviation Administration, 2012). In addition, the AIM provides specific directions regarding the pronunciations of letters and numbers. Despite this published guidance, pilots still misuse jargon which can cause conceptual errors, leading to serious problems and greatly affecting the accuracy of the readback (Cardosi, 1993).

Another common cause for readback errors is the length of messages transmitted by ATC. Long messages are difficult for the pilot to remember (Morrow, 1994; Krivonos, 2007). Often long messages cause the pilot to commit intrusion errors, which occur when data, typically numbers, from previous messages get mixed up with data in the current message. This effect is compounded when ATC sends pilots messages that deviate from normal procedures or use non-standard phraseology (Prinzo & Britton, 1993). Long messages and messages that include non-normal language and non-standard phraseology are typically defined as "complex" messages, as they increase the workload of the pilot attempting to process them (Cardosi, 1996; Prinzo & Britton, 1993). Furthermore, Cardosi (1993 & 1997) noted that complexity can also increase depending on the environment, the format and wording of messages, and the perceived pilot workload.

In addition, as the complexity of a message increases, the pilot's percentage of requests for a message repeat also increases (Morrow, Lee, & Rodvold, 1993). Although necessary for accurate transmissions, with an increase in repeats for long messages, the pilot occupies more time on the radio frequency, consequently blocking other transmissions and causing controllers to have to rush with other pilots' clearances to make up the lost time.

Communication issues and language. There are also many language factors that influence communication in the cockpit, such as use of phraseology, diction, speech rate, and comprehension (Estival & Molesworth, 2011). All of these factors have a greater impact when the pilot or controller is communicating in a language that is not his or her primary language. A study conducted by Estival and Molesworth indicated that the top five tasks in an ESL aviation environment include: understanding other pilots, remember what to say on the radio, giving proper readbacks, actually saying what the pilot needs to say, and understanding ATC. In addition, Estival and Molesworth found that in ESL environments, ESL pilots have a higher percentage of asking for repeats. Estival and Molesworth found that these communication issues were not influenced by the pilot's native language, nor by the number of years the pilot had been speaking English.

Prinzo and Hendrix (2008) conducted a study that looked at communication errors committed by native English speaking pilots and non-native English speaking pilots (ESL). Prinzo and Hendrix defined a communication error as "a situation in which a message is not understandable in content, speech (accent), structure, accuracy of readback, or any combination" of these elements that interferes "with ATC procedures." Prinzo and Hendrix examined the types of communication errors among pilots and categorized them as incorrect readbacks, requests for repeats, or breakdowns in communication. The researchers found that 23% of ESL pilot errors were due to readback inaccuracies, 62% were due to request for repeat, and 15% were due to breakdowns in communication. On the other hand, native English-speaking pilots had one readback error (<1%) and 34% request for repeats. The high percentage of request for repeat errors provides evidence for increased difficulty and lack of confidence of ESL pilots' ability to understand the ATC transmissions. Overall, Prinzo and Hendrix found that ESL pilots spent more time on the radio and caused more communication problems, with communication factoring into 75% of errors made by ESL pilots. Such language communication issues can lead to catastrophic events.

Language issues and accidents. Three of the most deadly accidents in aviation history occurred due to language related communications problems (Alderson, 2009; Estival & Molesworth, 2011):

Tenerife. In 1977 KLM and PanAm aircrafts collided on the runway due to the KLM pilots' misunderstanding of the controller's phraseology. The KLM pilots thought they had been given clearance to takeoff. Unfortunately the fogged conditions disabled the KLM pilots from seeing the PanAm plane that was still taxiing after landing. By the time the KLM pilots saw the PanAm flight, they were unable to stop and the two planes collided on the runway.

Avianca Flight 052. In 1990, Avianca Flight 052 crashed in New York due to the pilots' inability to effectively communicate to ATC that the plane was running out of fuel. The pilots only knew enough English to communicate for basic procedures and did not have the language skills to properly declare an emergency.

New Delhi. In 1996 a Kazakhstan aircraft and Saudi Arabian aircraft collided over New Delhi, India, due to the Kazakhstan pilots' language limitations as they were unable to fully understand the Indian air traffic controller. In addition, the Kazakhstan pilots' language limitations also prevented them from actively listening to the radio calls of other pilots (specifically the Saudi Arabian pilots) thus decreasing their situation awareness.

Accidents like these can occur for a number of reasons that stem from a lack of familiarity with plain English. Traditionally, not all countries required pilots and controller to learn English; countries only required pilots to learn aviation English, which is a specific set of phrases and terms used in aviation (Campbell-Laird, 2004). Prinzo and Hendrix (2008) found that controllers often use varying phrases in different countries, which may be confusing to people who are not as familiar with the language, a situation that occurred with the KLM pilots. This inability to communicate in plain English causes issues in unfamiliar and emergency situations when people tend to revert to plain language (Alderson, 2009; Campbell-Laird, 2004). In cases like the Avanica flight, this inability to communicate in plain English was catastrophic. In 2008, the International Civil Aviation Organization (ICAO) determined acceptable standards for proficiency of pilots in aviation English as well as plain English (Prinzo & Hendrix, 2008); however, the standards are still being validated and put into place (Alderson, 2009).

In order to counter act language deficiencies, some airspace is operated bilingually between the pilots and controllers (Stager, Proulx, Walsh, & Fudakowski, 1980). Although this addresses the communication issues between the pilot and controller, a bilingual environment creates additional difficulties for pilots. A study by Stager, Proulx, Walsh, and Fudakowski (1980) found that bilingual ATC environments are more susceptible to communication errors, with an increased number of incorrect readbacks, asks for repeats, extra calls, additional confirmation, and other added communications to clarify information. A survey conducted by Prinzo, Campbell, Hendrix, and Hendrix, (2010b; 2010c) also noted that pilots experience decreased situation awareness and increased workload in bilingual environments, as they are unable to understand the other pilots and have a harder time listening for callsigns.

Pilot techniques for receiving messages. Although ESL pilots have more communication errors than native English speaking pilots (Prinzo & Hendrix, 2008), a five part survey conducted by the FAA revealed that even native English-speaking pilots have difficulty in operating and understanding ATC in foreign countries (Prinzo & Campbell, 2008; Prinzo, Campbell, Hendrix, & Hendrix, 2010a; Prinzo, Campbell, Hendrix, & Hendrix, 2010b; Prinzo, Campbell, Hendrix, & Hendrix, 2010c; Prinzo, Campbell, Hendrix, & Hendrix, 2010d). Pilots indicated that communicating with ATC in foreign countries required more preparation and supplementary work, including consultation of maps and the Flight Management System (FMS) to help determine ATC instructions. The differences in phraseology, accent, and inflection add difficulty to communications causing the pilots to seek confirmation from other crew members as well as from textual references (FMS and sectionals).

Of the pilots surveyed, 54% indicated that they would prefer to have ATC messages sent in a textual modality to increase understanding (Prinzo & Campbell, 2008; Prinzo, Campbell, Hendrix, & Hendrix, 2010a; Prinzo, Campbell, Hendrix, & Hendrix, 2010b; Prinzo, Campbell, Hendrix, & Hendrix, 2010c; Prinzo, Campbell, Hendrix, & Hendrix, 2010d). In the Prinzo and Hendrix (2008) study, the most common communication problems were related to fluency and accent, both of which could be addressed through the use of textual modality. Other studies have suggested that the use of textual messages would be highly beneficial when language is an issue (Campbell-Laird, 2004).

Pilots have various strategies to help with communication. One manner in which pilots attempt to improve their recall of long or complex clearances is by writing the clearance on a piece of paper. That is, pilots use a shorthand, or type of notation, in order to capture the entire message, using it as a script to read back to ATC. In addition to writing, studies also show that pilots will try to improve their memory for long messages by giving ATC their callsign after the message readback (Morrow, 1994). While this may help the pilot to better remember the message as they are able to instantly regurgitate the information, this presents a problem for ATC as they have to wait until the end of the message to ensure that message is correct for that particular pilot. Pilots also attempt to ease their memory for long messages by condensing the message and reading it back out of order. In addition, pilots will also only readback part of a long message to ATC, known as a partial readback. Studies have shown that as the length of a message increases the percentage of partial readbacks increase, leaving hardly any messages receiving a full readback. Eighty-one percent of this change from full to partial readbacks is directly related to message length (Morrow, Lee, & Ravold, 1993).

Although it is not required that pilots read back all information (Airbus, n.d.), condensed or partial readbacks make it more difficult for the controller to accurately process and verify the transmitted information, thus reducing the chances of ATC catching errors in the readback (Morrow, 1994; Airbus, n.d.). Often pilots will readback the instructions they thought they heard, assuming that ATC will correct any mistakes in the readback (Cardosi, 1993). However, in a study examining pilot-ATC communications, Cardosi (1994) found that 40% of the erroneous readbacks the pilots transmitted caused a hearback error, meaning that the controller did not detect the error. This high percentage indicated the importance of pilots requesting a repeat of information when they do not hear the entire message.

The underlying issue is that pilots are given a lot of information in a short amount of time, making it difficult for the pilot to process the information and in turn, reducing the amount of information that is read back to ATC. A considerable amount of research exists involving how humans process information, and this literature has implications for ATC-Pilot communications. This will be described next.

Human Information Processing

Information processing is the process by which people obtain, make sense of, and store information from their environment. There have been many models of information processing and memory, but the first of the most well-known models involves a three-part memory “store” (Revlin, 2012). Atkinson and Shiffrin’s (1971) model was the first to utilize a three-stage processing model; these stages included a sensory store, a short-term store, and a long-term store. According to Atkinson and Shriffin’s model, the sensory store utilizes an unconscious process that extracts information from environmental stimuli and stores information for a very brief period until it is transferred to the short-term store. The person becomes aware of the environmental stimuli when the information is transferred to the short-term store. The short-term store uses special techniques to retain and process the information and has a relatively limited and brief capacity; it can store information for longer than the sensory store. Once processed, the information may pass to long-term store, which stores information for long periods of time and is available for later use. The process begins when a person focuses his or her attention on an environmental stimulus which acts on one of the sensory registers (visual, auditory, or haptic) (Atkinson & Shriffin, 1971). For pilots, the initial stimulus is typically an auditory signal in the form of the airplane’s callsign, followed later by a message containing instructions. Once the information has been processed, it can be retained in the long-term memory store, which has a large capacity and holds information for long periods of time, and some information possibly permanently.

Today, psychologists use a similar model to Atkinson and Shriffin’s (1971) “store” model, but in this new model, short-term and long-term store are referred to as short-term and long-term memory (Revlin, 2012). Similar to Atkinson and Shriffin, in this memory model, short-term memory refers to a person’s conscious and immediate thoughts, while long-term memory refers to the cognitive mechanism that holds a plethora of facts, knowledge, memories, and information that is accumulated throughout a person's lifetime (Revlin, 2012). This newer model also includes the concept of "working memory." Working memory acts as an interface between short-term and long-term memory as it "holds" the information that has been activated in long-term memory. Baddeley and Hitch (1974) describe working memory as an active component of memory that processes the information and Revelin (2002) added that working memory aids in learning new information. Working memory allows the environmental stimulus to be transferred from short-term memory and transformed into information that can be stored in long-term memory. Baddeley and Hitch's (1974) model also emphasizes the existence of a central executive mechanism that directs a person's attention and uses specific tactics to help remember and store information in long-term memory.

Often people have problems remembering information due to the limited capacity of short-term memory. Research shows that if information is received it will only remain in working memory for 30 s before it begins to decay (Cowan, 1994). This time limit of 30 s can vary with factors such as age, culture, and amount of information (Cowan, 1994). According to Brown and Peterson's research, information begins to decay immediately after presentation, with data suggesting that after 18 s of delay between presentation and recall, roughly 80-90% of the presented information is lost (Revlin, 2012). In aviation, many complex clearances can exceed 18 s, indicating that the crucial information contained could be lost without some mechanism of retention.

Rehearsal. Rehearsal involves paying attention to a stimulus in order to retain it in working memory and allowing for eventual encoding in long term memory (Revlin, 2012). There are two basic types of rehearsal: elaborative rehearsal and maintenance rehearsal.

Elaborative rehearsal involves expanding on information that already exists in long-term memory (Brown & Craik, 2000, in Revlin, 2012). For example, an individual may integrate old information with new information and thus, reorganize the information in long-term memory. In fact, while elaborative rehearsal is key to effective learning and skill acquisition, it may not be the primary technique used by pilots when they are trying to process clearances. When pilots write down clearances, it helps them to organize the information in a concise manner. This also prevents confusion with old clearance information.

In aviation, maintenance rehearsal is commonly used by pilots to help remember a clearance. Maintenance rehearsal occurs when an individual repeats a list over and over (Revlin, 2012). This list can consist of a variety of data types including names, numbers, or other concepts. Although this type of rehearsal aids memory, its use does not always guarantee that the information is encoded and remembered (Glenberg, Smith, & Green, 1977, as cited in Revlin, 2012). This rehearsal strategy can cause pilots to become distracted by instructions given to other pilots on the radio or by activities in the cockpit thus disrupting the repetition and the sequence causing the pilot to forget what he or she is rehearsing.

The use of the maintenance rehearsal method is heavily reliant on the phonological loop component of working memory (Baddeley, 2000, as cited in Revlin, 2012). The phonological loop is the mechanism of working memory that processes auditory information and stimuli. The use of the phonological loop allows for internal auditory rehearsal of words, as occurs in the maintenance rehearsal method.

Incorporating new information into the phonological loop. During rehearsal, the phonological loop is disrupted when an individual attempts to incorporate new information. That is, if the individual pays attention to new stimuli, this can interrupt current processing mechanisms that are active in working memory (Cowan, Wood, Negent, & Treisman, 1997). The newly discovered information can influence and interfere with the current information that is being processed. This disruption can lead to memory deficits and lost content. For example, when a pilot is trying to remember a sequence of directions, if a new turn is introduced into the sequence, the pilot must pause his or her phonological loop to incorporate this new turn. This process of incorporating new information is highly susceptible to memory errors.

Memory errors. In recall tasks, people either make errors of commission or errors of omission. Errors of commission occur when the person adds an item to the recall that was not present in the initial presentation (Gobet & Simon, 1996). Omission occurs when a piece of information from the original sequence is forgotten or not included in the recall. Pilot-ATC communication issues can also be categorized as errors of commission and errors of omission. For pilots, errors of commission can involve switching the order of numbers in a frequency, while errors of omission can involve missing a piece of transmitted information. Gobet and Simon (1996) showed that people with more experience are more likely to make errors of commission while people with less experience are more like to make errors of omission. In addition to measuring errors, Gobet and Simon's experiment (2000) allowed participants to select "unknown" when they felt they could not recall anymore. This "unknown" option directly relates to when pilots state "say again" on the radio, or ask for a repeat. Results from Gobet and Simon's study showed that experienced individuals chose "unknown" significantly less than inexperienced individuals. This is likely played out in ATC-pilot communication as novice pilots have to state "say again" more often than expert pilots.

Novice pilots are also more likely to be less confident in their ability to accurately process ATC clearances, thus causing them to have more memory issues than their expert counterparts. These memory deficits are often more prominent when the sequence to be recalled includes long words, or words that take longer to pronounce (Cowan, 1994); this is known as the length effect (Romani, McAlpine, Olson, Tsouknida, & Martin, 2004).

Word length. The content of the rehearsal sequence, such as word complexity and word length, greatly influence and limit the effectiveness of the phonological loop (Cowan, 1994). This interference occurs as longer words take up more time in the phonological loop during the maintenance rehearsal process. By taking up larger portions of time in the phonological loop, these longer words increase the time between the rehearsal of the other elements in the phonological loop, thus decreasing the amount of recall of all the words in the sequence.

In addition, the length effect is more prominent when the time between the information presentation and information recall is brief (Romani et al., 2004). As the time between presentation and recall increases, so does the opportunity for rehearsal. Shorter words are pronounced more quickly, allowing the whole sequence to be rehearsed in a shorter period of time. This faster rehearsal rate leads to increased recall (Tehan & Tolan, 2006). Shorter words also improve recall when the order of information is important (Tehan & Tolan, 2006). Most order loss is due to forgetting words in a sequence (omission) or replacing digits with guesses (commission), not an actual movement of words to different locations in the sequence (Bunting, 2006).

Although longer words, in general, disrupt the verbal memory process, length can help enhance recall when only a portion of the stimuli needs to be recalled (Romani et al., 2004). Longer words are easier to recall if only fragments are presented because, even with fragments missing, there is still more available information than in fragments of shorter words.

The length effect is also enhanced when a person attempts to write the words in a sequence (Romani et al., 2004), as it takes longer to write longer words. In aviation, many clearances contain long instructions such as “frequency” and “direct to.” These longer terms are often abbreviated using a shorthand that allows the pilot to shorten longer words to just a couple of letters. These abbreviations can act as a cue for both immediate and later recall. Studies have shown that the recall for longer words is significantly better if the learner is presented with a cue to recall the longer word (Tehan & Tolan, 2006).

Complexity of information, or difficult concepts, on the other hand, can also help with recall (Cowan et al., 1997). When complex information is taken into memory it requires more effort to encode; this increase in effort creates a more distinct recall mechanism that allows for easier recall.

Multiple modalities. According to Baddeley’s model of working memory (1992), processing information in two sensory modalities, such as visual and auditory, enhances overall processing and capacity of working memory (Tabbers, Martens, & van Merriënboer, 2001). This enhanced processing allows for better retention and recall. One way to encode using two different modalities is to write the word and say it aloud, allowing for the use of both modalities when encoding the information (Benbasat, Suh, & Lee, 2001). Using two modalities to encode information allows for more accurate recall by creating a distinct memory trace in long term memory (Conway & Gathercole, 1990).

One of the first studies to look at the multiple modality effect was Conway and Gathercole’s (1990) study that tested participant’s recall on words that they heard and then wrote as opposed to those that were presented and rehearsed in a visual only (heard and internally rehearsed) or text only (visually presented and then written) format. The result of the study indicated that people not only learn better when they use multiple modalities, but also that participants in the listening and writing condition had better memory for words both when they were intentionally trying to learn the list as well as when they were given no instruction regarding memorizing the list (i.e., unintentional recall). This indicated that the writing of spoken words helped with both intentional and incidental learning.

Additional research indicated that the two language sensory modalities, auditory and visual, have distinct benefits and limitations. According to Lee et al (2001), auditory information is beneficial for dynamic or changing information (Revlin, 2012). In comparison to visual information, auditory information “grabs” attention and requires less mental effort to process (Tabbers et al., 2001) and allows for better immediate memory and recall (Crooks, Cheon, Inan, Ari, & Flores, 2012). The downside to auditory processing is that it is more susceptible to false alarms and incorrect recall (Pierce, Gallo, Weiss, & Schacter, 2005). For example, when presented with a list of words, people are more likely to falsely remember a related word when the information is presented orally as opposed to visually. This increase in error rate may be due to auditory information’s dynamic nature as well as humans’ decreased capacity for processing auditory information, as only 30% of human processing can focus on the processing of auditory information (Revlin, 2012). Overall, auditory processing is highly beneficial but severely limited.

Encoding and recall of visual information, on the other hand, has been shown to require higher mental effort (Tabbers et al., 2001), but is better for long term memory and recall (Crooks et al., 2012). Lee et al., (2001) found that a visual stimulus is better used to present static and unchanging information (Revlin, 2012). A visual presentation lends itself better to stable and consistent information, which is important for decision making and review of complex information. Stable information (Crooks et al., 2012) allows for more detailed and item specific processing (Pierce et al., 2005) which is important with complex items and decisions.

Overall, both sensory modalities present multiple benefits and limitations in the accurate recall of information. Therefore, the use of both modalities can help to improve overall processing and recall (Conway & Gathercole, 1997; Revlin, 2012; Tabbers et al., 2001; Pierce et al., 2005; Crooks et al., 2012).

In aviation, clearances are presented in an auditory format, which coincides well with the use of auditory information to grab the pilot's attention, but the information given in a clearance can be relevant for many minutes or even hours and across many miles. Therefore, it is important that this information is retained. Pilots who write down the clearances give themselves a more stable, visual representation of the information that they can access at a later time. Thus, pilots attempt to use dual modality to help remember this essential information.

External memory aids. One type of cue is a memory aid. A memory aid is a tool or mechanism that is used to enhance and improve memory (Block & Morwitz, 1999). Memory aids can come in the form of tangible tools such as lists, diaries, and alarms or intangible mechanisms such strategies and associations. Memory aids are typically divided into two categories. These include internal and external; internal memory aids refer to internal cognitive mechanisms, while external memory aids include concrete tools and devices (Block & Morwitz, 1999; Liu, Chen, Melara, & Massara, 2008).

In 2001, Walker and Andrews conducted a study in which college students were given personal data assistants (PDAs) for a semester to utilize as external memory aids. At the end of the semester Walker and Andrews compared these students' academic performance and remembrance of events and numbers to a control group that did not use external memory aids. Results indicated that not only do people frequently use external memory aids, but those that use external memory aids tend to have improved memory and academic performance. Most students used the external memory aid as a reminder for prospective memory. The study indicated that external memory aids can help increase memory, especially in conditions where people experience stress, confusion, and distraction, all of which contribute to memory errors. The study also noted that students had difficulty retrieving information from the external memory aids when they used confusing and unrelated notation to record information. This reiterates Harris's (1980) finding that memory aids must be related to what they represent. For pilots, if the notation they use to write down the clearance is not legible or rushed it could render the memory aid unintelligible and invalid.

Liu et al. (2008) suggests that memory aids are more effective in unfamiliar environments, further supporting the idea that memory aids are more beneficial to those with less experience and less ability to utilize familiar environmental cues. In these unfamiliar environments, memory aids can increase signal detection and efficiency by providing quick reminders and important information. The utilization of external memory aids, such as a visual representation of ATC messages in the cockpit, would be extremely beneficial to bilingual pilots who have the added complexity of processing in a secondary language.

Itons-Peterson found that people use memory aids when they need to accurately reconstruct information (Block & Morwitz, 1999). Itons-Peterson notes that it is important to use external memory aids when a person expects competing information to disrupt processing and interfere with memory.

External memory aids are a simple way to preserve the accuracy of data, thus helping to reduce the possibility of interference (Block & Morwtiz, 1999). Interference is a phenomenon that occurs when information presented conflicts with pervious knowledge of information (Revlin, 2012). For example, in aviation when a pilot receives a new clearance he or she may confuse the information in the new clearance with information from the previous clearance. When people try to recall data that they cannot remember, the incorrect data interferes with actual data, contaminating recall (Bunting, 2006). While rehearsal may improve working memory and recall, if rehearsing incorrect data, the person may only become more confused.

External memory aids also help with interruptions as they act as a tangible and reliable tool that can help a person find his or her place or retain information after an interruption (Block & Morwtiz, 1999). Another type of difficulty in recall is when interruptions occur. Interruptions are events that occur during the encoding process that affect recall (Oulasvirta & Saariluoma, 2006). According to Oulasvirta and Saariluoma, rehearsal is a poor strategy to use for retaining information because it has a high disruption tolerance, or a high susceptibility to loss of information after interference. Oulasvirta and Saariluoma note that a person can increase their interruption tolerance through practice.

Novice pilots have less experience (i.e. practice) listening to and responding to clearances, putting them at a disadvantage. Add to this the difficulty of translating the message for pilots where English is not their first language, and the task of ATC-pilot communications becomes increasingly difficult.

English as a Second Language

As the population in America grows, with it there is an increase in the bilingual (speaking two languages) and multilingual (speaking multiple languages) population. This creates a more diverse society as more people with English as a second language (ESL) and English as a foreign language (EFL) enter the workforce in America. ESL typically refers to individuals who have received formal training and or academic instruction in English, while EFL refers to individuals who have learned English colloquially through social interactions, but have never received formal training (Oxford, 2003). For the purpose of this study, ESL will be the principle focus. In addition, when referring to bilingual people the primary language, or language the individual learned first, is referred to as L1, while the secondary language, or language that was learned second, is referred to as L2.

Many studies have shown that despite formal training and education, bilingual individuals do not process information as efficiently as they do in their primary language (e.g. Francis & Gutiérrez, 2012; Gollan, Montoya, Cera, & Sandoval, 2008).

Processing in L2. Studies have shown that processing information in a second language requires increased time and effort when compared with monolinguals processing information, or with bilinguals processing information in their primary language (e.g. Francis & Gutiérrez, 2012; Gollan at al., 2008).

Processing high and low frequency words. One of the things that impacts processing speed and ability is the frequency that words are used (e.g. Francis & Gutiérrez, 2012; Gollan at al., 2008). People tend to process high frequency words, or words that are used daily, more rapidly than low frequency words, words that are used rarely. This frequency effect is magnified when the person is processing in L2 as opposed to L1. According to researchers, this may be attributed to the reduced exposure of bilinguals to L2 words.

Francis and Gutiérrez (2012) showed that processing information in L2 requires greater cognitive resources. In their study, Francis and Gutiérrez examined bilinguals processing high frequency versus low frequency words. In addition, the researchers evaluated the participants' ability to recall words in comparison with ability to recognize words. The researchers found that the participants were faster and more accurate at identifying low frequency words in L2 when they had to recognize them as opposed to recall them, while when identifying words in L1 there was no significant difference between recognition and recall. From their study, Francis and Gutiérrez concluded that bilinguals could more accurately and quickly process in L2 when recognition was required due to the less complex and singular nature of recognition which focuses on one item at a time, versus recall tasks which requires associative processing.

Gollan et al. (2008) also examined bilingual processing in L2 of high frequency and low frequency words. In their experiment, Gollan et al. compared monolingual to bilingual processing in L2 of high frequency and low frequency words; in addition, they studied young and old bilinguals. Gollan et al. found that bilinguals process words more slowly with a more significant difference in the processing of low frequency words. Surprisingly, the researchers did not find a significant difference in age group processing, despite the fact that the older group had over 50 years more experience with both languages than the younger group, giving them more exposure to low frequency words and making them bilingual experts. From their research, Gollan et al. concluded that despite the level of experience and expertise, bilinguals can never truly achieve L2 equivalency to L1 and will always slightly suffer in processing capabilities and speed.

Memory capacity in L2. Studies have shown that in addition to slower processing, bilinguals have a reduced memory capacity in L2. One study compared digit span of bilinguals in L1 compared to digit span in L2 (da Costa Pinta, 1991). Results showed that participants had a significantly longer digit span in L1 compared to L2. One explanation for this increased capacity is that in L1, bilinguals can receive and process the information more rapidly, allowing them to abbreviate it and encode it into working memory more rapidly before the onset of memory decay. As L1 is the primary language, the participants had more practice in taking and abbreviating words in L1 and therefore could abbreviate larger chunks of information at once. This skill is especially important for pilots as they try to take in the clearance information and abbreviate it so it can be internally rehearsed more efficiently. This decreased processing ability in L2 could prove to be detrimental for a pilot's ability to accurately remember a complex clearance.

Translation and semantic processing. Another variable that factors into increased L2 processing is unconscious translation of words and semantic processing, even when no verbal or semantic processing is required to perform a task (e.g. Martin, Costa, Dering, Hoshino, & Wu, 2012; Wu & Thierry, 2012). In one study, Wu and Thierry (2012) gave bilingual Chinese (L1) participants a nonverbal task as well as a verbal task to complete. Both tasks contained English (L2) words, but one task did not require the participants to utilize the words and therefore reading them was unnecessary. The researchers recorded the time it took participants to complete each of the two tasks. The researchers found that the tasks (verbal vs. nonverbal) took the same amount of time even though the nonverbal tasks required significantly less processing and mental effort, as no translation was required. The results of this study suggest that bilinguals unconsciously translate into L1 even when the task does not require verbal analysis, which may help to explain the increased processing time on nonverbal L2 tasks.

Martin et al. (2012) found that increased reaction time may also be due to unnecessary semantic processing and translation from L2 to L1 on tasks that do not require semantic processing. In their experiment, the researchers had English-Welsh bilinguals (English as L2) and English monolinguals compare the spelling of words and pseudo words to determine if the presented item was a word or not. This task required merely looking at the letters of the word, but not semantically processing the meaning of the word itself. Martin et al. found that bilinguals have significantly greater reaction times, which they attributed to unnecessarily translating and semantically processing all presented items. These results indicate that bilinguals will always have an increased processing time, as they will always have the extra reaction time due to internal translation time.

Problems listening in L2. In addition to decreasing reaction time due to increased cognitive load when processing in L2, bilinguals also show difficulty processing auditory signals (Broersma & Cutler, 2008; Field, 2004) which is especially critical for pilots when processing clearances that are time sensitive. Listening in a second language may be more difficult as it requires more activation and effort (Broersma & Cutler, 2008) to decode less familiar words and speech patterns. In one study, Broersma and Cutler asked Dutch bilinguals (English as L2) and English monolinguals to listen to a series of items that contained words and non-words. After listening to an item, the participants were asked to determine if it was a word or non-word. The results showed that bilingual participants were more likely to accept non-words as words. Bilingual participants also had a longer reaction time, indicating more intense processing. Not only could increased reaction time for auditory processing prove to be a time issue with ATC-pilot communications, but mishearing a word could lead to serious and even potentially fatal errors.

In another study, Field (2004) found that L2 listeners tend to not only mishear words more often, they also tend to be less confident in what they are hearing. This reduced confidence in what they hear causes most bilinguals to either replace the word with a similar sounding word or input what they expect to hear (Field, 2004), which is a common problem with pilot-ATC communications (Cardosi, 1996).

The increased auditory processing (Broersma & Cutler, 2008; Field, 2004) by bilingual pilots in L2 environments could also lead to increased workload and stress as pilots are required to process and respond in a very limited time frame.

Differences in orthography. Another factor that influences processing in L2 is orthography (Akamatsu, 1999; Nguyen-Hoan & Taft, 2010; Weber, Broersma, & Aoyagi, 2011). Orthography involves the way words are written and spelled, as well as the rules of pronunciation and spelling. Studies have shown that bilinguals with a primary language that is orthogonally and alphabetically different from English face additional challenges when processing English words.

One study looked at the effects of accents on L2 comprehension (Weber et al, 2011). In the study, researchers compared Japanese and Dutch bilinguals' ability to comprehend auditory messages when presented with an American, Japanese, and Dutch accent. Results showed that the participants had the best accuracy and comprehension when the accent mirrored their own. Furthermore, the Dutch participants more easily understood the American accent than the Japanese accent, while the Japanese participants had an equally difficult time understanding the Dutch and American accents. From these results, Weber et al. concluded that the changes in the phonetic alphabetic (i.e., Japanese to Dutch or English or vice versa) imposed increased challenges in listening comprehension. More specifically, researchers attribute the difference in vowel sounds as a major contributor to mishearing words and misinterpretations. As the airline industry grows to encompass an increasing amount of pilots and controllers who have a primary language with an alphabet that varies from English (i.e., Chinese, Japanese, Arabic, etc.), this issues with listening comprehension across accents and cultures could lead to increased problems in auditory processing for pilot-ATC communications.

One study that looked at variances in orthography compared Chinese and Japanese bilinguals, Persian bilinguals, and English monolinguals' ability to read text that used case alternations (e.g., cAsE aLtErNaTiOn) (Akamatsu, 1999). Chinese and Japanese alphabets are drastically different from the English alphabet and English words, while the Persian alphabet is similar to the English alphabet. While the English monolinguals had significantly faster reactions times and more efficient processing, the Persian participants also showed significantly faster processing compared to the processing of Japanese and Chinese participants. These results suggest that L1 orthography plays a role in L2 processing. Akamatsu concluded that the similar orthography of the Persian language to the English language gave Persian participants a processing advantage. Bilinguals whose L1 is drastically different from the L2 must learn a new, secondary way to read and process information and therefore their overall processing time and effort required is increased. The Akamatsu study implies that it would be more difficult for bilingual pilots of an orthographically different L1 to use written memory aids in the cockpit, as even textual information requires additional processing.

Unfortunately, as stated previously, despite years of training and experience, L2 processing can never truly be equivalent to L1 (Gollan et al., 2008), and there is no exception when processing items orthographically (Nguyen-Hoan & Taft, 2010). In their study, Nguyen-Hoan and Taft used participants that were born, raised, and educated in an English (L2) environment. Despite their years of expertise, participants were still shown to be at a disadvantage when completing spelling-to-dictation and auditory awareness tests. Nguyen-Hoan and Taft attributed the poor performance on L2 tasks to the "competition model" which states the way information is orthographically processed in L1 will always affect and influence a person's language perception. Therefore, according to the competition model, if a person's L1 is significantly different orthographically from the person's L2, the person will always be negatively impacted when processing words in L2. For pilots this means that although L2 processing may be improved with practice and training, ESL pilots will never be able to process auditory clearances with the speed and efficiency of monolingual pilots or bilingual pilots with English as L1.

Despite the inability of ESL bilinguals to ever truly achieve language equivalency (Gollan, et al., 2008; Nguyen-Hoan & Taft, 2010), there are mechanisms that have been shown to improve L2 processing, such as the use of the visual channel.

Using the visual channel to improve L2 processing. Many studies have researched the use of the visual channel to help improve auditory and general processing. Wagner (2010) refers to a multitude of studies that have examined the use of video and pictures to help ESL students better understand auditory conversations and instructions. Both the study that Wagner performed and the studies that he reference indicate that using the visual channel has a positive impact on listening comprehension. While the use of videos in the cockpit to aid in ATC-pilot communications seems obtrusive and extraneous, these results can be generalized to imply that the use of visual (i.e., textual messages) may be beneficial in the cockpit.

According to Taft (1986) there is a distinct difference in the way that people process auditory and visual information. In his experiments, Taft had participants distinguish between words and non-words when presented both orally and visually. From his studies, Taft concluded that spoken words tend to be identified by the first few phonemes, regardless of syllable structure. These phonemes can be simply singular letters, a single syllable or can encompass multiple syllables. Visual words, on the other hand, are usually identified by the first orthographically defined syllable or Basic Orthographic Syllabic Structure

(BOSS). This difference in processing may explain why visual and auditory learning strategies can produce different results.

In his work, Oxford (2003) indicates that there are many elements that can impact language learning, such a personality, motive, and instructional strategy. An instructional strategy is the method that the instructor uses to convey the information. Three of the most common strategies are: visual (use of pictures and written words), auditory (use of speaking and listening), and kinesthetic (use of body movements and actions).

According to Oxford (1995, as cited in Tight, 2010), 50-80% of learners prefer visual instruction to auditory and kinesthetic, with kinesthetic being the least preferential mode of instruction. In his study, Tight looked at the performance of ESL students under the three types of instruction (visual, auditory, and kinesthetic) as well as a mixed modality that included all three types of instruction. Tight also took into account the learner's preferred mode of learning. The results indicated that a mixed modality produced the highest level of understanding and learning. In addition, only the group that preferred visual instruction showed significantly improved performance in their preferred mode of instruction, while those that preferred auditory and kinesthetic instruction showed no added benefit when the instructor only used this method of instruction.

Another study by Lund (1991) showed that using auditory and visual channels also provided distinct differences in comprehension and leaning. In his study, Lund had ESL students listen to a conversation as well as read a passage. What Lund found is that when ESL students listen they tend to recall main ideas and general concepts; whereas when they read, on the other hand, they tend to recall greater details. These differences in comprehension and learning may be influenced by the nature of the listening and reading tasks. Listening tasks exist in time and therefore, the listener can only interpret what is being immediately presented to them, causing them to focus on key words, phrases, and concepts. Reading tasks, on the other hand, allow the reader the advantage to go back and review information, allowing the processing of information in more singular units; this allows readers to better remember details. Lund implies that combining reading and listening into one task could help improve learners' overall comprehension as well as their knowledge of details. This combination could also help to improve confidence in the learner's processing ability. For pilots communicating with ATC, confidence and accuracy are essential to understanding clearances and therefore, pilots may benefit from a mixed modality presentation.

Benefits of bilingualism. Although presenting information in a mixed modality may provide additive processing because auditory and visual information are processed in different ways (Taft, 1979; Taft, 1986), bilinguals have shown advantages in processing that may aid in multimodal processing (Blumenfeld & Marian, 2011; Ransdell, Srecco, & Levy, 2001).

Blumenfeld and Marian (2011) compared the performance of monolinguals and bilinguals in their ability to select the correct word in their L1. In the experiment, researchers gave participants a square with four images with two of the images having phonetic similarity (e.g. plum and plug). The participants listened to the target word and then had to select the image that displayed that target. The researchers used eye tracking to monitor the participants' delays and fixations on certain objects (i.e. the similar sounding object). The results showed that bilinguals (in their L1) have a greater ability to focus on the target and ignore distracting and extraneous information, while monolinguals, on the other hand, tend to linger longer on distracter terms. Although their results can only be applied to linguistic tasks, Blumenfeld and Marian concluded that monolinguals have greater ability to ignore distractors and focus on the main tasks when performing linguistics tasks in their L1.

In another study conducted by Ransdell, Srecco, and Levy (2001), researchers compared the performance of monolinguals and bilinguals (in L2) performing verbal and nonverbal tasks with secondary distracter tasks. In this study, researchers only examined bilingual experts, or individuals who had been practicing both languages for a long period of time. The results showed that bilinguals performed better on the primary tasks (verbal and nonverbal) and were less distracted by the secondary task than monolinguals. Ransdell, Srecco, and Levy attributed these results to the fact that expert bilinguals have spent the majority of their lives with two competing languages, causing them to constantly have to suppress one language. This suppression gives bilinguals more practice and experience ignoring stimuli that distract from the primary task. These results suggest that while ESL pilots may have added difficulty from auditory processing, their increased ability to multitask may allow them to benefit from the usage of visual aids in the cockpit such as a mixed modality/redundant message system.

Data Link in the Cockpit

From the beginning of pilot-ATC cockpit communications, voice transmission has been the primary method of exchanging messages. In recent years, researchers have explored the possibility of using synthetic speech in the cockpit as well as replacing auditory messages with visual messages for ATC communications (Hakkinen & Williges, 1984; Hilborn, 1972; Latorella, 1998; Wickens, Sandry, & Vidulich, 1983).

Synthetic speech. Auditory messages and signals in the cockpit have been shown to prevent pilots from averting their gazes (Hilborn, 1972). Some studies have investigated the use of synthetic speech in the cockpit as opposed to a human controller (Hakkinen & Williges, 1984; Hilborn, 1972). Hilborn found that synthetic speech can be beneficial, as one can control the rate, tone, and pitch of speech; but overall, Hilborn found that having a speech component in the cockpit proved to be beneficial to the pilot. Hakkinen and Williges (1984) examined the use of a synthetic speech component for standard auditory messages as well as auditory warning messages. The researchers found that participants had faster response times when all information was presented in an auditory format as opposed to emergency messages alone. From their study, Hakkinen and Williges suggested that further research be conducted regarding the use of visual messages in addition to auditory messages in the cockpit.

Visual ATC messages. With the recent interest in using visual messages in the cockpit, researchers have become concerned regarding the impact of visual messages in the cockpit on pilots' situation awareness, mental workload, and flying performance. Latorella (1998) compared the effects of auditory and visual messages on pilots' procedures and performance in flight. Latorella found that orally presented messages resulted in interruptions producing three times more procedural errors than visually presented messages. Latorella attributed this to the time sensitivity of auditory messages, as opposed to visual messages that are permanent and can be handled at the pilot's leisure. However, despite the difference in time sensitivity, Latorella found no significant difference in time to resume a task after responding to an ATC message.

Similarly, McGann, Morrow, Rodvold, and Mackintosh (2009) found that the time sensitivity of auditory messages affect pilots' responses. In their study, McGann et al. found that auditory messages produced faster response times for pilots. This can be attributed to the time sensitivity as well as the ability of auditory messages to grab the pilot's attention. These researchers found that when messages were presented visually, pilots took longer to respond. Response durations increased when two messages were transmitted in close succession. This increased response time could be attributed to the lack of urgency conveyed by a written messages, as the visual messages remained available throughout the duration of the flight.

Mixed modality ATC messages. In addition to studies focusing on the benefits of auditory only and visual only messages, researchers have also examined the benefits of transmitting and displaying information across multiple modalities (Helleberg & Wickens, 2009; Lancaster & Casali, 2008; Wickens & Liu, 1988; Wickens, Sandry, & Vidulich, 1983). Wickens et al. (1983) noted as workload increases, the benefit of utilizing multiple modalities for input and output of information also increases. With increased workload comes the possibility of competing resources; using multiple modalities can help to combat these issues and increase efficiency of processing (Wickens at al., 1983). According to research, verbal tasks benefit more from the use of multiple modalities while spatial tasks tend to provide more interference with other forms of processing, leading to decreased performance during multimodal processing (Wickens at al., 1983; Wickens & Liu, 1988). Wickens et al. (1983) also found that it is easier to multitask when the tasks are compatible with one another. For example, if ATC messages are presented both visually and orally, the two complementary tasks should enhance one another to produce faster and more accurate processing than the use of only one of the modalities.

Another study compared the use of visual only, auditory only, and mixed modality ATC messages (Helleberg & Wickens, 2009). This study demonstrated that visual messages provided the best understanding and flight performance, while auditory messages led to the worst performance. In their experiment, Helleberg and Wickens compared pilot performance in aviation ability (flight path and outside scanning), navigation, and communication. They concluded that the auditory only condition used more visual resources than the visual only condition as the pilots attempted to write down the messages, thus leading to poorer performance overall. Surprisingly, the mixed modality condition did not lead to improved results over the visual condition. Based on results, the researchers suggested that with proper training the pilots could greatly benefit from the mixed modality format.

In contract, a study by Lancaster and Casali (2008) did show superior results of a mixed modality messaging system compared with auditory only and visual only presentations. In their study, Lancaster and Casali not only found pilots to have improved performance in the mixed modality condition, they also concluded that when using mixed modalities, the pilots experienced reduced workload and increased situation awareness. The researchers concluded the textual information alone may be more distracting and take longer to read. However, with the auditory message to accompany the visual message (redundant messaging), pilots would have the advantage of auditory time sensitivity in addition to the advantage of clarity and permanence of the visual message.

Implications for ESL pilots. Ease of processing using a mixed modality may help to alleviate workload (Lancaster & Casali, 2008), especially in pilots who experience increased processing and workload due to processing in L2. The visual component of the message also helps by virtually eliminating the need for clarifications (McGann, et al., 2009), which would be highly beneficial for ESL pilots who commonly experience more mishears when processing in L2 (Broersma & Cutler, 2008; Field, 2004).

Summary of the Literature

Even the most experienced pilots have difficulty overcoming the challenge of communication during flight. Poor pilot-ATC communications is a major problem in the aviation industry as it can be linked to over 70% of aviation incidents (Connell, 1996). Furthermore, effective communication can be influenced by a number of pilot factors including stress, fatigue, distraction, and an individual's ability to process information (Morrow, 1994). Studies have shown that pilots with a greater capacity in short-term memory have more accurate readbacks to ATC and require fewer clarifications (Morrow & Prinzo, 1999). Studies have also shown that subject matter experts can surpass those with above average cognitive ability in recall (Morrow et al., 2005). Experience can improve communication skills, but even expert pilots can have difficulty with accurate readbacks due to the limitations of working memory.

Many studies have examined cognitive processes to determine what methods people use to process and store information. Research has shown benefits for using mixed modalities to increase overall processing (Tabbers et al., 2001). Tabbers et al. (2001) argue that auditory information grabs a person's attention and requires less mental effort to process; however, this information may be more susceptible to errors (Pierce et al., 2005). Visual processing, on the other hand, has been shown to help improve long term memory and recall (Crooks et al., 2012). In addition to visual processing, external memory aids, which typically include visual information, can improve performance in unfamiliar environments (Liu et al., 2008). Therefore, the use of visual processing and memory aids in addition to auditory processing may prove to be more beneficial for people that experience increase mental processing difficulties, such as ESL pilots.

ESL pilots have an added difficulty processing ATC transmissions. Even bilinguals who have been speaking in L2 their entire lives do not show equivalent mastery of L2 in comparison with monolinguals (Gollan et al., 2008; Nguyen-Hoan & Taft, 2010). Not only does processing in L2 take longer (Broersma & Cutler, 2008), but ESL individuals have more limited working memory (da Costa Pinta, 1991) and slower reaction times (Martin, et al., 2012). In addition, ESL individuals have increased difficulty with listening tasks and demonstrate more mishears and are more inaccurate acceptance of non-words as words (Broersma & Cutler, 2008; Field, 2004; Weber, Broersma, & Aoyagi, 2011). Increased difficulty in processing gives ESL pilots a disadvantage processing ATC clearances.

Mixed modality data link messages in the cockpit is one method that is being explored to reduce pilot workload and increase the accuracy of pilot readbacks. Studies have shown that visual messages allow for permanence of messages, which can decrease workload and increase readback accuracy (McGann, et al., 2009). Mixed modality of ATC messages, presented both orally and visually, have also shown to reduce workload and improve situation awareness (Lancaster & Casali, 2008). Using mixed modality may prove to have an additive benefit for ESL pilots by reducing an already higher workload and clarifying mishear issues through supplementary visual messages.

Purpose of the Study

The present study compared the performance of monolingual, English-speaking pilots to bilingual, ESL pilots on standard ATC cockpit communication tasks. Pilots recieved a variety of ATC clearances common to the en route phase of flight presented either as a spoken phrase, the auditory condition, or presented as both a spoken phrase and text-based message on a display, the mixed-modality condition. Based on previous research, it was predicted that ESL pilots would have a slower response time to ATC messages on average than monolingual pilots. In addition, for both pilot groups, the mixed-modality condition was expected to result in better performance than the auditory condition; however, this advantage was expected be more pronounced for ESL pilots than for monolingual pilots. Specifically, three hypotheses were tested:

- Hypothesis 1: ESL pilots would exhibit significantly longer response times to ATC messages than monolingual pilots.
- Hypothesis 2: Both monolingual and bilingual pilots would exhibit significantly fewer readback errors in the mixed-modality condition than in the auditory-only condition.
- Hypothesis 3: ESL pilots would exhibit a significantly larger reduction in readback errors in the mixed-modality condition, in comparison to readback errors in the auditory condition, than monolingual pilots.

Method

Design

The study used a 2 x 2 mixed design consisting of one between-subjects factor and one within-subjects factor. The between-subjects factor was language background (monolingual vs. bilingual). The within-subjects factor was the communication modality (auditory vs. mixed). The two dependent variables included the accuracy of pilots' readback, measured as a weighted total converted into a weighted percentage score, and the pilot's response time, measured in tenths of a second, between the end of the ATC message and the start of the pilots' readback. Therefore, two dependent variables (accuracy and response time) were analyzed for both the modality and language conditions.

Participants

A total of 40 pilots from a southeastern university in the United States were used in this study. Pilot ages ranged from 17-30 years old and the sample population consisted of 10% female pilots and 90% male pilots. Pilots were assigned into two groups of 20 pilots each based on language background (monolingual vs. bilingual). ESL language backgrounds included: Arabic (7.5%), Cantonese (2.5%), German (2.5%), Gujarati (2.5%), Hawsa (2.5%), Japanese (2.5%), Korean (10%), Spanish (12.5) and Thai (2.5%). All pilots were flight students with approximately 40 to 150 flight hours, with 77.5% of the population having between 50 and 100 flight hours. All pilots held a student pilot license; 65% of the pilots had a private pilot license and 15% of the pilots had an IFR rating. The lower number of flight hours was intended to minimize the amount of experience each pilot had with ATC communications and thus, increase the amount of processing and workload required for communications.

Apparatus

During the experiment, pilots performed basic flight procedures in a flight training device which utilized round dial displays. The pilots wore a headset through which the ATC clearances were transmitted. When present, textual messages were sent in real time simultaneously with the auditory messages and were displayed on a secondary display using a small monitor placed near the throttle. All ATC clearances were extracted from real ATC files pertaining to the Daytona Beach area found on LiveATC.net. This ensured that all pilots received the same, realistic messages. Clearances were presented intermittently with radio traffic. All pilot responses were recorded using a hand-held recording device mounted on the cockpit below the round dial displays. The pilots were also given a kneeboard, providing them the option to copy down clearances if desired. Prior to the flight assessment, pilots were given 10 min to study a Jacksonville sectional map that encompasses the Daytona Beach airspace.

The Pilots received 20 real ATC clearances pertaining to the Daytona Beach area; 10 clearances were presented in an auditory format, and 10 were presented in the mixed-modality format containing both a visual and auditory instantiation of the same message. The clearance modality did not follow a consistent pattern, but instead, was varied randomly. All participants experienced the same variation of modality. All clearances were IFR low altitude clearances with a VFR flight plan. A list of the ATC clearances used in this experiment can be found in Appendix A. The clearances presented in each condition have similar length and complexity, to ensure that both groups of clearances present the same overall level of challenge to the pilots.

Measures

Demographics. Demographic data was collected via a survey (see Appendix B) that included general information, language experience, and flight experience. Specifically, questions related to language addressed pilots' level of familiarity and training with English; whereas, the questions related to flight experience addressed pilots' total number of flight hours and amount of flight experience.

Language Assessment. All pilots were required to take a brief language assessment prior to the actual experiment. The language test was an excerpt from a practice test for the International English Language Testing System (IELTS). The IELTS is a nationally recognized test that is an admissions standard for measuring English competency by over 7,000 institutions in 135 countries (International English Language Testing System, 2012). Studies have demonstrated that scores on the IELTS positively correlate with academic achievement and success at English-speaking institutions (Huong, n.d.). The ILETS is a four-part test that consists of listening, reading, writing, and speaking sections. For the purpose of this study, only portions of the listening and reading sections were used as the pilots were required to listen and read ATC messages. A copy of the language assessment can be found in Appendix C.

Accuracy Score. Each of the pilot's readbacks were recorded and scored based on the accuracy of each transmitted piece of information in comparison to the original clearance transmitted. Each piece of information received a weighted point value of 1, 3, or 5. A weight of 1 indicates that the information is superfluous and it is not required that the information is read back. A weight of 3 indicates that the information is helpful to the pilot and therefore is desired to be read back but is not required. A weight of 5 indicates that the information is crucial to pilot-ATC communication and is required to be read back. Figure 1 below shows an example scoring for a clearance used in the present study. All pilots' readbacks were recorded, transcribed, and scored based on the scoring sheet in Appendix D. The scoring system was developed with the help of a retired ATC controller, and the weights of 1, 3, and 5 were chosen to create greater separation between the different types of information. The scoring system was designed specifically to rate the accuracy of readback of student pilots, as all pieces of information are scored although not all pieces of information are required in the readback. For student pilots who are still learning how to properly communicate with ATC, it is important that they read back all information to practice radio calls and ensure proper procedures. The individual scores from the different elements were summed and divided by the total points possible to get the weighted accuracy score for each clearance, displayed as a percentage.

Modality	Clearance	Readback	Score
Auditory	Riddle 4-4-0 thank you, radar contact, climb VFR to 2-thousand, turn left heading 2-5-0, vectors ILS	Climb VFR	/1
		2-thosuand	/5
		Left	/3
		250	/5
		Vectors ILS	/1
		Callsign	/5
		Total:	**/20**

Figure 1. Example clearance scoring system

Reaction Time. Reaction time was measured as the interval, in tenths of a second, between the end of each ATC transmission to the beginning of the pilot's response. A small secondary speaker playing ATC messages was placed near the handheld recorder. The placement of the speaker enabled the recorder to record the ATC clearances and the pilot's responses on the same sound file. The sound file was uploaded to computer using Sony Sound Organizer, which produced a visual sound wave of the recorded file. The sound wave allowed for an accurate assessment of response time. This response time shows how long it took each participant to receive and process each clearance.

Procedure

Pilots were assessed on an individual basis. Each pilot began the study by reading the participant instructions (Appendix E) and signing an informed consent (Appendix F). The experimenter then briefed the pilot to explain the general purpose of the experiment. The briefing information was read from a script to ensure that all pilots received the same information; the script was read in parts before each portion of the experiment and can be found in Appendix G. The pilot then filled out the demographics survey followed by completion of the language assessment. The language assessment took approximately 20 min and was used to assure that all pilots had a similar level of English comprehension and listening abilities. The results of the language assessment were used to ensure that there were no significant group differences in basic language ability. Following the language assessment, the pilot was given 10 min to study the Jacksonville sectional which encompasses the Daytona Beach area; the pilots were not required to use the full 10 min. After studying the map, the pilot completed a 10 min practice session that allowed him or her to become familiar with the flight training device and experience sample clearances. The sample clearances were real ATC clearances for the same callsign used in the assessment and also pertained to the Daytona Beach area. In the practice session, the pilot encountered four clearances, two auditory and two mixed modality.

After completing the initial assessments and training session, the pilot began the actual experiment. The experimental flight began with the pilot in a mid-air position to avoid the added complexity of creating a flight plan, taxiing, and taking off. The experiment took approximately 30 min to complete as the pilots were presented with 20 clearances. The pilots were asked to verbally respond to all ATC clearances as well as perform the flight maneuvers that corresponded with each clearance. Each clearance was presented for approximately 5-10 s via audio transmission and 15-20 s via textual transmission. All clearances were spoken in a voice with a generic American accent and were taken from real ATC transmissions found on liveATC.net. When present, the textual transmission appeared simultaneously with the audio transmission. After completing the experiment, pilots were debriefed and allowed to ask any questions.

Results

Each pilot's responses were recorded, transcribed, and scored for accuracy using the scoring rubric found in Appendix D. Results were analyzed in two ways; first, examining each pilot's weighted total accuracy scores and reaction times and, second, comparing the composite scores of the two measures calculated as an accuracy to speed ratio.

For the analysis of the weighted accuracy scores and reaction times, the weighted accuracy scores were averaged based on clearance type (auditory vs. mixed) to determine an overall weighted total auditory accuracy score and an overall weighted total mixed accuracy score for each participant. These measures will henceforth be called the auditory accuracy score and the mixed accuracy score. In addition, each pilot's reaction time for each clearance was calculated, in s, and compiled into averages by clearance type. These measures will henceforth be called auditory reaction time and mixed reaction time. The results of the group averages can be found in Table 1. In addition, Figures 2 and 3 display the group averages with the error bars representing two standard errors from the mean.

A mixed, two-way multivariate analysis of variance (MANOVA) was used to compare the main effect of the within-subjects factor of clearance type (auditory and mixed) and the main effect of the between-subjects factor of group (bilingual and monolingual) on the two dependent measures of accuracy and reaction time. Results indicated that there was a significant main effect for the clearance type, $F(1, 38) = 16.609$, $p < .000$, $\eta^2 = .304$, *power* = .978, however there was no significant main effect for group. Furthermore, the interaction between the clearance type and the participant group was not significant, $F(1, 398) = .454$, $p < .505$, $\eta^2 = .012$, *power* = .101. Post hoc MANOVAs revealed that the significant main effect of clearance type was due to differences in the accuracy scores, $F(1, 38) = 17.108$, $p < .000$, $\eta^2 = .310$, *power* = .981. Pilots' reaction time scores did not significantly contribute to the main effect of clearance type, $F(1, 38) = 1.657$, $p < .206$, $\eta^2 = .042$, *power* = .241. Post hoc ANOVAs for each clearance type revealed that there was no main effect for either condition across participant groups (auditory, $F(1, 38) = .400$, $p < .531$, $\eta^2 = .010$, *power* =.095; mixed, $F(1, 38) = 2.746$, $p < .106$, $\eta^2 = .067$, *power* = .365).

The results of the MANOVAs indicate that both groups had significantly better accuracy scores for the mixed modality clearances than they did for the clearances that were only presented in an auditory format. The group means displayed in Table 1 also indicate that accuracy scores for the monolingual group were higher than the scores for the bilingual group, however this difference was not statistically significant. Similarly, the reaction time scores for the monolingual group were smaller (i.e., faster) for the monolingual group than the bilingual group but this difference was not significant. Although not statistically significant, the bilingual group did have a better average reaction time in the mixed condition which contradicts the results of the monolingual group that had a slightly better reaction time in the auditory condition.

Table 1

Group Average Accuracy Scores and Reaction Times

	Group	Mean	Std. Deviation	N
Auditory Accuracy Score	Monolingual	76.8075	14.71145	20
	Bilingual	74.0836	12.42247	20
	Total	75.4456	13.51006	40
Mixed Accuracy Score	Monolingual	87.0380	8.60546	20
	Bilingual	81.5910	11.91832	20
	Total	84.3145	10.62484	40
Auditory Reaction Time	Monolingual	1.4652	.31392	20
	Bilingual	1.6951	.68548	20
	Total	1.5802	.53896	40
Mixed Reaction Time	Monolingual	1.4754	.46994	20
	Bilingual	1.5227	.55557	20
	Total	1.4990	.50846	40

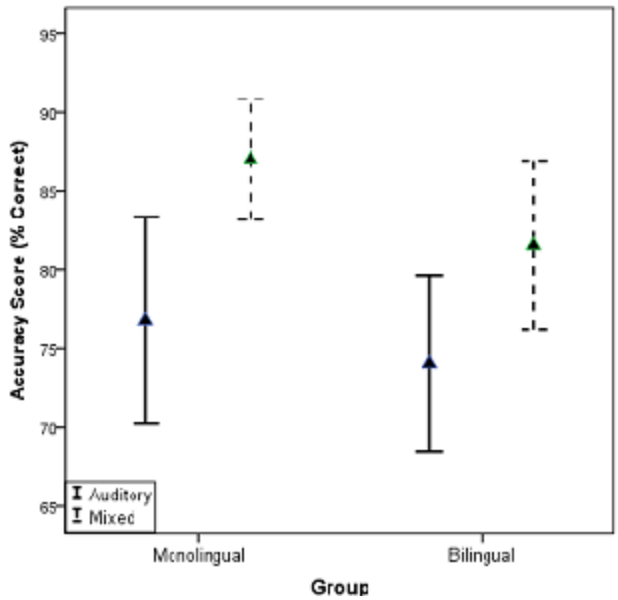

Figure 2. Range of accuracy scores

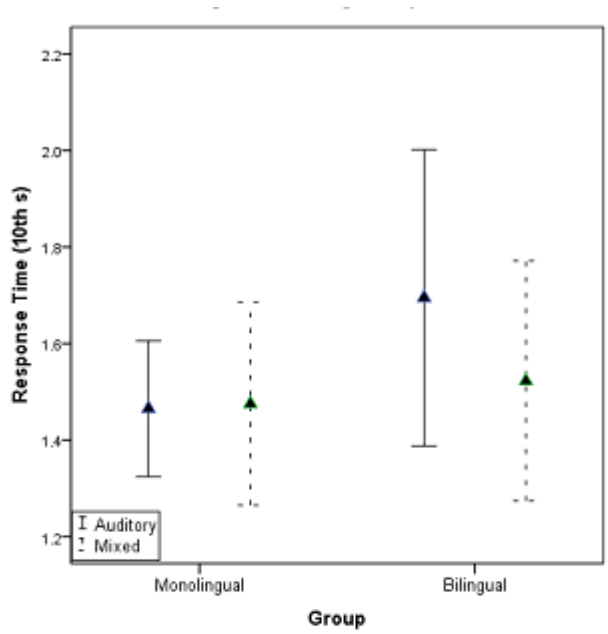

Figure 3. Range of response times

For the analysis of the composite scores, the accuracy score for each readback was divided by the reaction time for that readback, creating an accuracy to speed ratio for each clearance. These ratios were averaged by clearance type (auditory or mixed) to get an average ratio for each participant. These measures will henceforth be called auditory composite score and mixed composite score. The results of the group averages can be seen in Table 2. In addition, Figure 4 displays the group averages with the error bars representing two standard errors from the mean.

A mixed MANOVA was used to compare group performance for the two clearance conditions. The results indicate that there was a significant main effect for the clearance type, $F(1, 38) = 17.233$, $p < .000$, $\eta^2 = .312$, *power* = .981, but there was no significant interaction between clearance type and group, $F(1, 38) = .026$, $p < .872$, $\eta^2 = .001$, *power* =.053. The post hoc ANOVAs for auditory and mixed clearance type across groups yielded no significant results (auditory, $F(1, 38) = 1.144$, $p < .292$, $\eta^2 = .029$, *power* = .181; mixed, $F(1, 38) = .734$, $p < .397$, $\eta^2 = .019$, *power* = .133).

The results of the composite score MANOVAs support the results of the initial MANOVAs indicating that there was a significant difference between the two clearance types, as the mixed clearance produced significantly better results. These differences, however, were not statistically different between language groups. As in the initial results, Table 2 also indicates that the monolingual group performed better than the bilingual group in both conditions.

Table 2

Group Average Composite Scores

	Group	Mean	Std. Deviation	N
Auditory Composite Score	Monolingual	72.7316	20.61154	20
	Bilingual	65.5704	21.72728	20
	Total	69.1510	21.21569	40
Mixed Composite Score	Monolingual	89.1769	33.84759	20
	Bilingual	80.7779	27.87538	20
	Total	84.9774	30.89961	40

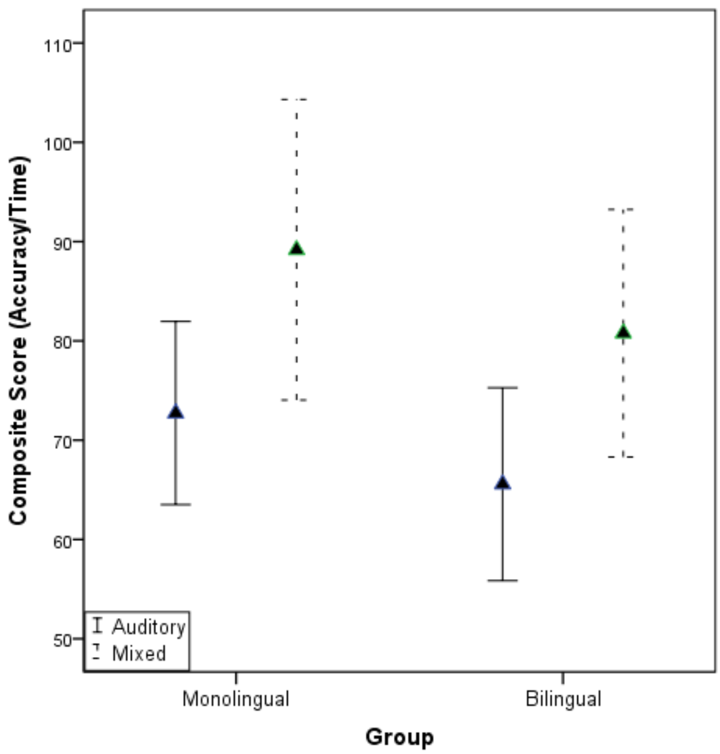

Figure 4. Range of composite scores

The results were also analyzed for variations in accuracy scores, response times, and composite scores based on each pilot's level of piloting experience (student only, private, or private with IFR) and each pilot's score on the language test. No significant results were found, indicating that the pilots' accuracy scores and response times did not vary with pilot experience or with performance on the language assessment.

Discussion

Results of the present study revealed that overall there was no significant difference between the ESL pilots and the monolingual pilots on performance. In contrast to the first hypothesis, ESL pilots did not exhibit longer reaction times than monolingual pilots. Likewise, results did not support the third hypothesis that ESL pilots would show a larger increase in accuracy, measured as a greater reduction in readback errors, in the mixed modality condition than monolingual pilots. However, results did support the second hypothesis as both groups of pilots showed better accuracy in the mixed modality condition than in the auditory condition.

These results do contrast findings from previous research in that ESL pilots in the present study did not exhibit significantly longer reaction times. For example, Francis and Gutiérrez (2012) and Gollan et al. (2008) predicted that pilots would have longer reaction times due to increased effort and time required to process information in a L2). However, Cardosi and Boole (1991) conducted a study that examined time critical pilot-ATC communications in terms of general communication duration and pilot response times. The researchers found that average pilot response time ranged from 2.7 s to 3.3 s with standard deviations ranging from approximately 4.6 s to 6.3 s. In the results of the current study, pilot response times ranged from 1.5 s to 1.7 s across all four conditions with standard deviations ranging from .3 s to .7 s. Although response time can vary with communication complexity and situation (Cardosi & Boole, 1991), the lack of variability of response times in this study compared to the results of Cardosi and Boole's study further supports the lack of significant group differences for response times.

A visual comparison of mean accuracy scores also suggests that monolinguals had better accuracy than bilinguals; however, the analysis found no significant group differences for accuracy scores. The lack of statistical significance may be due to the relatively small amount of flight experience across both groups. According to Prinzo and Hendrix (2008), the ESL pilots should have committed more communication errors. Prior research also indicated that ESL pilots would perform more poorly due to their decreased memory capacity in L2 (da Costa Pinta, 1991). This decrease in memory capacity is due to lack of familiarity with aviation terminology. By using novice pilots, both groups may have had a low level of familiarity with the aviation terminology used in pilot-ATC communications. In addition, Estival and Molesworth (2011) found that ESL pilots have more communication errors during flight due to decreased understanding. The non-significance between group errors may be attributed to both groups' lack of familiarization with IFR flight rules. Most of the pilots' flight time may have been with an instructor, causing them to rely on the instructor's knowledge and experience. This lack of familiarity across groups may have attributed to the absence of significant differences between groups, thus supporting the premise that communication errors are due to misunderstanding and lack of familiarity.

Although the present study did not find significant group differences, the present results did align with previous findings that ESL pilots would perform better with a visual modality (Broersma & Cutler, 2008; Field, 2004; Estival & Molesworth, 2011). These findings (e.g., Broersma & Cutler, 2008; Field, 2004) suggest ESL individuals have greater difficulty processing L2 auditory signals. Although not significant, the trend of ESL pilot response times in the present study indicated that further research may be necessary to explore the impact of mixed modality ATC messages on response time and to explore the correlation between reaction time and confidence. Furthermore, researchers suggest that increased difficulty of processing L2 may be attributed to an increase in the number of mishears. The superior performance of ESL pilots in the mixed modality condition indicates that the presentation of the visual message along with the auditory message may decrease the number of mishears as it provides clarifications and confirmation. The increased accuracy of ESL pilots in the mixed modality condition also suggests an increase in confidence.

In addition to improving performance in ESL pilots, the present results suggest that a mixed modality presentation would benefit monolingual pilots. According to a pilot survey conducted by the FAA, 54% of experienced native English-speaking pilots said that they would prefer to receive ATC messages in a textual format especially when operating in ESL airspaces (Prinzo & Campbell, 2008). Some researchers have speculated that using a mixed modality in the cockpit could be distracting and thus increase workload (Wickens et al., 1983).However, the FAA survey, pilots indicated that factors such as accent and unfamiliarity can contribute to workload and add difficulty in communication (Prinzo & Campbell, 2008). Therefore, by using a mixed modality, the pilots could communicate with more confidence, allowing for decreased workload and smoother communications. Pilots stated that when they fly in unfamiliar foreign countries they often use maps, the FMS, and other crew members to verify ATC's instructions. The use of a mixed modality in the cockpit would eliminate the need to consult multiple sources, which diverts the pilot's attention, and allow the pilot to better focus on flight.

The FAA survey was just one of many studies that have examined the impact of visual messages in the cockpit on communications and pilot performance (Latorella, 1998; Lancaster & Casali, 2008). Consistent with the results of the present study, Latorella (1998) found that the use of visual ATC messages led to a reduced number of errors. In the present study the use of a visual modality improved the accuracy of both pilot groups indicating that it allows for pilots to not only be more accurate in their responses, but the increased composite score indicates that with a mixed modality pilots are more accurate without a significant effect on response time. Furthermore, Lancaster and Casali (2008) found that using the visual modality for ATC messages can improve overall pilot performance. By using a mixed modality, as opposed to a purely visual modality, pilots can consult the visual message only when it is necessary for clarifications. The use of a mixed modality would allow for pilots to better multitask while in fight, thus allowing for more attention to be attributed to the flight task while communicating.

Limitations

Although this study suggests mixed modality has performance benefits to all pilots, the results did not show a significant difference between ESL and monolingual pilots. One factor that may have contributed to the lack of significance was the sample population. All ESL pilots used in the present study were flight students at an English-speaking flight school in the United States. Due to this setting, these ESL pilots are exposed to English not only during their flights, but also in their classes and while socially interacting with the surrounding community. Such increased exposure to not only aviation English, but also plain English, likely provides greater familiarity with English for pilots in this study than would be experienced by ESL pilots learning to fly in other countries.

Another factor that may have influenced the results is the equipment used to conduct the study. The secondary monitor displaying the clearances was not located centrally in the cockpit; therefore, its placement increased the effort required to monitor the display. Subjective observations by researchers noted that pilots had to divert their vision to the secondary monitor, not only confirming the pilots' use of the monitor, but also indicating that the display could be more beneficial if located elsewhere. Theoretically, if a screen displaying ATC clearances was available, it should be mounted somewhere in the cockpit that is in close proximity to other displays that must be monitored frequently.

Further Research

Although not statically significant, the trend of the results indicate that further research is warranted to explore the benefits of adding mixed modality presentation of clearances for the benefit of ESL pilots or for American pilots operating outside the United States. Further research should investigate the effect of a mixed modality presentation on ESL and monolingual pilots with more flight experience, to eliminate the unfamiliarity of pilot-ATC communications for both groups. In addition, future research could incorporate ESL pilots learning to fly in ESL countries, as opposed to the type of pilot population used in the present study. The ICAO is currently working to improve communications among ESL pilots (Prinzo & Hendrix, 2008); the use of a mixed modality for ATC message may prove to be beneficial for this target audience. Furthermore, the FAA has been working on data link in the cockpit for years. Further research should focus on the best way to implement this new technology. Researchers should investigate the best location in the cockpit to place a display and in what format the clearances should be presented (i.e. abbreviated, full sentences, etc.). Researchers have also suggested the need for training when new technology such as this is implemented (Hellberg & Wickens, 2009). Overall, the implementation of mixed modality messages in the cockpit could improve the quality of communications, but many studies still need to be conducted before the implementation of technology for mixed modality messages.

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Appendix A

Clearances

Clearances for Assessment

Modality	**Clearance**
Auditory	Riddle 4-4-0 thank you, radar contact, climb VFR to 2-thousand, turn left heading 2-5-0, vectors ILS 7 left
Mixed	4-4-0 missed approach from the ILS, fly runway heading, climb VFR to 2-thousand, return to 1-2-5-.-8
Mixed	Riddle 4-4-0, turn left heading 1-6-0
Auditory	Riddle 4-4-0 is 1-0 miles from Daytona, turn left to a heading of 0-9-0, maintain 1-thousand 3-hundred until established cleared ILS, runways 7 left approach
Auditory	Riddle 4-4-0, Daytona Approach radar contact, climb VFR to 2-thousand
Auditory	Riddle 4-4-0, turn left heading 3-5-0
Mixed	4-4-0 heading 3-4-0 you may see company Twinstar 10 o'clock is now 6 miles off of Ormond, maybe be climbing stopped at 15-hundred, no factor
Mixed	Riddle 4-4-0, turn heading 3-5-0
Auditory	4-4-0, company Twinstar is 10 o'clock to you less than a mile, 1-thousand 6-hundred, indicated that he should be descending back to 15-hundred
Auditory	Riddle 4-4-0 turn left heading 2-5-0
Mixed	Riddle 4-4-0, turn left heading 2-3-0
Mixed	Riddle 4-4-0 turn left heading 1-8-0, join the VOR 1-6 final
Mixed	Riddle 4-4-0 remaining at 1-thousand 6-hundred until 2 miles south of the Ormond VOR, cleared VOR 1-6 approach, circle left at Daytona for runway 7 left
Auditory	Riddle 4-4-0 Contact Tower 1-2-0-.-7
Mixed	4-4-0 be advised the runway 7 left edge lights east of November 5 are out of service
Auditory	Riddle 4-4-0 traffic Skyhawk, 2 and a half mile final
Auditory	4-4-0 cancel approach clearance, continue left downwind runway 7 left, traffic out 2 mile final
Mixed	Riddle 4-4-0 follow the traffic, he's going to go a miss over I-95, runway 7 left cleared to land
Mixed	4-4-0 you can start your base turn now, traffic will go a miss in about a half a Mile
Auditory	Riddle 4-4-0, turn left at November 3, then contact ground, traffic company Skyhawk 1 mile final

Appendix B

Demographics Survey

Demographics Survey Participant #_________

Please select that answer that best fits.

General Information:

Gender

☐ Female

☐ Male

Age

☐ Younger than 18

☐ 18-22

☐ 23-26

☐ 27-30

☐ Older than 30

Language Information:

Language

☐ English (monolingual) **skip to the Flight Experience Section**

☐ Bilingual; Primary Language: ____________________________

Have you ever received formal English Language training/education

☐ Yes, number of years: ________

☐ No

Number of years speaking English

☐ 1-5

☐ 5-10

☐ 10-15

☐ 15-20

☐ More than 20

Number of years living in the U.S.

☐ Less than 1

☐ 1-5

☐ 5-10

☐ 10-15

☐ 15-20

☐ More than 20

What percentage of the week do you speak **English**

☐ Less than 20%
☐ 20-40%
☐ 40-60%
☐ 60-80%
☐ 80-100%

Flight Experience:

Years Flying

☐ Less than 1 year
☐ 1-2 years
☐ 2-5 years
☐ 5-10 years
☐ More than 10 years

Total Flight Hours

☐ 40-50
☐ 50-60
☐ 60-70
☐ 70-80
☐ 80-90
☐ 90-100
☐ 100-110
☐ Other ______________________

Current Flight Ratings and Certificates

☐ Private pilot
☐ Commercial pilot
☐ VFR Rated
☐ IFR Rated
☐ Other ______________________________________

Have you completed a solo flight

☐ Yes
☐ No

Have you had an IFR training

☐ Yes
☐ No

Appendix C

Language Assessment

Language Assessment

SECTION 1 Questions 1-10

Questions 1 – 6

Circle the correct letters **A – C**

> Example
>
> Mr. Griffin is coming for…
>
> A a holiday
> (B) a business trip
> C to see family

1. Mr. Griffin has been to the Sunrise Hotel…

   A once previously.
   B twice previously.
   C three times previously.

2. Mr. Griffin is from…

   A Melbourne.
   B Sydney.
   C Perth.

3. Mr. Griffin's passport number is…

   A 87647489.
   B 87637289.
   C 87637489.

4. Mr. Griffin wants to book…

   A a single room for 2 nights.
   B a double room for 2 nights.
   C a single room for 1 night.

5. Mr. Griffin will arrive at the Sunrise Hotel at…

   A 9.15 pm.
   B 10.00 pm.
   C 9.35 pm.

6. When he gets to the Sunrise Hotel, The food Mr. Griffin will find in his room will be…

   A a cheese sandwich with fries.
   B a cheese sandwich.
   C a burger.

Questions 7 – 10

Write **NO MORE THAN THREE WORDS OR A NUMBER** for each answer.

7. What number room will Mr. Griffin be in at the Sunrise Hotel?

   ____

8. How much will Mr. Griffin pay per night at the Sunrise Hotel?

   $______________________

9. Who will take Mr. Griffin's food to his room?

   ____

10. How much will Mr. Griffin pay for his food?

   $______________________

SECTION 2 Questions 1-11

Read the passage and then answer **Questions 1 – 14**

DIABETES

Here are some facts that you probably didn't know about diabetes. It is the world's fastest growing disease. It is Australia's 6th leading cause of death. Over 1 million Australians have it though 50% of those are as yet unaware. Every 10 minutes someone is diagnosed with diabetes. So much for the facts but what exactly is diabetes?

Diabetes is the name given to a group of different conditions in which there is too much glucose in the blood. Here's what happens: the body needs glucose as its main source of fuel or energy. The body makes glucose from foods containing carbohydrate such as vegetables containing carbohydrate (like potatoes or corn) and cereal foods (like bread, pasta and rice) as well as fruit and milk. Glucose is carried around the body in the blood and the glucose level is called glycaemia. Glycaemia (blood sugar levels) in humans and animals must be neither too high nor too low, but just right. The glucose running around in the blood stream now has to get out of the blood and into the body tissues. This is where insulin enters the story. Insulin is a hormone made by the pancreas, a gland sitting just below the stomach. Insulin opens the doors that let glucose go from the blood to the body cells where energy is made. This process is called glucose metabolism. In diabetes, the pancreas either cannot make insulin or the insulin it does make is not enough and cannot work properly. Without insulin doing its job, the glucose channels are shut. Glucose builds up in the blood leading to high blood glucose levels, which causes the health problems linked to diabetes.

People refer to the disease as diabetes but there are actually two distinctive types of the disease. Type 1 diabetes is a condition characterized by high blood glucose levels caused by a total lack of insulin. It occurs when the body's immune system attacks the insulin-producing beta cells in the pancreas and destroys them. The pancreas then produces little or no insulin. Type 1 diabetes develops most often in young people but can appear in adults. Type 2 diabetes is the most common form of diabetes. In type 2 diabetes, either the body does not produce enough insulin or the cells ignore the insulin. Insulin is necessary for the body to be able to use sugar. Sugar is the basic fuel for the cells in the body, and insulin takes the sugar from the blood into the cells.

The diagnosis of diabetes often depends on what type the patient is suffering from. In Type 1 diabetes, symptoms are usually sudden and sometimes even life threatening - hyperglycaemia (high blood sugar levels) can lead to comas – and therefore it is mostly diagnosed quite quickly. In Type 2 diabetes, many people have no symptoms at all, while other signs can go unnoticed, being seen as part of 'getting older'. Therefore, by the time symptoms are noticed, the blood glucose level for many people can be very high. Common symptoms include: being more thirsty than usual, passing more urine, feeling lethargic, always feeling hungry, having cuts that heal slowly, itching, skin infections, bad breath, blurred vision, unexplained weight change, mood swings, headaches, feeling dizzy and leg cramps.

At present there is no cure for diabetes, but there is a huge amount of research looking for a cure and to provide superior management techniques and products until a cure is found. Whether it's Type 1 or Type 2 diabetes, the aim of any diabetes treatment is to get your blood glucose levels as close to the non-diabetic range as often as possible. For people with Type 1 diabetes, this will mean insulin injections every day plus leading a healthy lifestyle. For people with Type 2 diabetes, healthy eating and regular physical activity may be all that is required at first: sometimes tablets and/or insulin may be needed later on. Ideally blood glucose levels are kept as close to the non-diabetic range as possible so frequent self-testing is a good idea. This will help prevent the short-term effects of very low or very high blood glucose levels as well as the possible long-term problems. If someone is dependent on insulin, it has to be injected into the body. Insulin cannot be taken as a pill. The insulin would be broken down during digestion just like the protein in food. Insulin must be injected into the fat under your skin for it to get into your blood.

Diabetes can cause serious complications for patients. When glucose builds up in the blood instead of going into cells, it can cause problems. Short term problems are similar to the symptoms but long term high blood sugar levels can lead to heart attacks, strokes, kidney failure, amputations and blindness. Having your blood pressure and cholesterol outside recommended ranges can also lead to problems like heart attack and stroke and in fact 2 out of 3 people with diabetes eventually die of these complications. Young adults age 18 - 44 who get type 2 diabetes are 14 times more likely to suffer a heart attack, and are up to 30 times more likely to have a stroke than their peers without diabetes. Young women account for almost all the increase in heart attack risk, while young men are twice as likely to suffer a stroke as young women. This means that huge numbers of people are going to get heart disease, heart attacks and strokes years, sometimes even decades, before they should.

Questions 1 – 7

Do the following statements reflect the views of the writer in the Diabetes passage?

In the space provided to the number write:

YES *if the statement agrees with information*

NO *if the statement contradicts the statement*

NOT GIVEN *if there is no information on this in the passage*

____________ 1. Carbohydrate foods are the body's source of glucose.

____________ 2. Diabetics cannot produce insulin.

____________ 3. Sometimes patients develop diabetes due to faults in their own immune systems.

____________ 4. Hyperglycemia leads to type 1 diabetes being diagnosed quite quickly.

____________ 5. Artificial insulin is the most effective treatment for those patients requiring insulin.

____________ 6. Frequent check ups at the doctor can drastically reduce the chances of suffering from problems related to diabetes.

____________ 7. The majority of diabetics develop heart problems and suffer strokes.

Questions 8 – 11

Complete the following statements (questions **8 – 11**) with the best ending from the box below.

In the space provided next to the numbers **8 – 11** write the appropriate letters **A - H**:

____________ 8. Bizarre as it may seem, may people with diabetes…

____________ 9. Insulin is a hormone that allows glucose to be absorbed by…

____________ 10. Non severe type 2 diabetes can be solely treated by…

____________ 11. Increases in diabetes related heart problems are mainly seen in…

A	a healthy lifestyle.
B	never suffer any ill effects.
C	women.
D	people also suffering strokes.
E	body cells.
F	the pancreas.
G	do not realize the fact.
H	injections.

Appendix D

Scoring Sheet

Modality	Clearance	Readback	Score
Auditory	Riddle 4-4-0 thank you, radar contact, climb VFR to 2-thousand, turn left heading 2-5-0, vectors ILS	Climb VFR	/1
		2-thosuand	/5
		Left	/3
		250	/5
		Vectors ILS	/1
		Callsign	/5
		Total:	**/20**
Mixed	4-4-0 missed approach from the ILS, fly runway heading, climb VFR to 2-thousand, return to 1-2-5-.-8	Missed approach from ILS	/1
		Runway heading	/5
		Climb VFR	/1
		2-thousand	/5
		125.8	/3
		Callsign	/5
		Total:	**/20**
Mixed	Riddle 4-4-0, turn left heading 1-6-0	Left	/3
		160	/5
		Callsign	/5
		Total:	**/13**
Auditory	Riddle 4-4-0 is 1-0 miles from Daytona, turn left to a heading of 0-9-0, maintain 1-thousand until established cleared ILS, runways 7 left approach	10 miles from Daytona	/1
		Left	/3
		090	/5
		Maintain	/1
		1-thousand	/5
		Until established	/1
		Cleared ILS	/3
		Runway 7 left approach	/1
		Callsign	/5
		Total:	**/25**
Auditory	Riddle 4-4-0, Daytona Approach radar contact, climb VFR to 2-thousand	Climb VFR	/1
		2-thousand	/5
		Callsign	/5
		Total:	**/11**
Auditory	Riddle 4-4-0, turn left heading 3-5-0	Left	/3
		350	/5
		Callsign	/5
		Total:	**/13**
Mixed	4-4-0 heading 3-4-0 you may see company Twinstar 10 o'clock is now 6 miles off of Ormond, maybe be climbing stopped at 15-hundred, no factor	340	/5
		Twinstar	/.25
		10 o'clock	/.25
		6 miles off Ormond	/.25
		15 hundred	/.25
		Looking/traffic in sight	/1
		Callsign	/5
		Total:	**/11**
Mixed	Riddle 4-4-0, turn heading 3-5-0	350	/5
		Callsign	/5
		Total:	**/10**

Modality	Clearance	Readback	Score
Auditory	4-4-0, company Twinstar is 10 o'clock to you less than a mile, 1-thousand 6-hundred, indicated that he should be descending back to 15-hundred	Twinstar	/.25
		10 o'clock	/.25
		1-thouand 6-hundred	/.25
		15 hundred	/.25
		Looking/traffic in sight	/1
		Callsign	/5
		Total:	**/6**
Auditory	Riddle 4-4-0 turn left heading 2-5-0	Left	/3
		250	/5
		Callsign	/5
		Total:	**/13**
Mixed	Riddle 4-4-0, turn left heading 2-3-0	Left	/3
		230	/5
		Callsign	/5
		Total:	**/13**
Mixed	Riddle 4-4-0 turn left heading 1-8-0, join the VOR 1-6 final	Left	/3
		180	/5
		VOR 1-6 final	/5
		Callsign	/5
		Total:	**/18**
Mixed	Riddle 4-4-0 remaining at 1-thousand 6-hundred until 2 miles south of the Ormond VOR, cleared VOR 1-6 approach, circle left at Daytona for runway 7 left	1-thousand 6-hundred	/5
		2 miles S of Ormond VOR	/3
		VOR 1-6 approach	/5
		Circle left at Daytona	/5
		Runway 7 left	/5
		Callsign	/5
		Total:	**/28**
Auditory	Riddle 4-4-0 Contact Tower 1-2-0-.-7	Roger	/1
		120.7	/3
		Callsign	/5
		Total:	**/8**
Mixed	4-4-0 be advised the runway 7 left edge lights east of November 5 are out of service	Roger	/1
		Runway 7 left	/.25
		Edge lights	/.25
		East November 5	/.25
		Out of service	/.25
		Callsign	/5
		Total:	**/6**
Auditory	Riddle 4-4-0 traffic Skyhawk, 2 and a half mile final	Skyhawk	/.5
		Half mile final	/.5
		Looking/traffic in sight	/1
		Callsign	/5
		Total:	**/6**
Auditory	4-4-0 cancel approach clearance, continue left downwind runway 7 left, traffic out 2 mile final	Cancel approach clearance	/5
		Left downwind runway 7L	/5
		Traffic	/1
		Callsign	/5
		Total:	**/16**

Modality	Clearance	Readback	Score
Mixed	Riddle 4-4-0 follow the traffic, he's going to go a miss over I-95, runway 7 left cleared to land	Follow traffic	/5
		Amiss over I-95	/1
		Runway 7 left	/5
		Cleared to land	/5
		Callsign	/5
		Total:	**/21**
Mixed	4-4-0 you can start your base turn now, traffic will go a miss in about a half a mile	Turn base/starting base	/1
		Roger	/1
		Callsign	/5
		Total:	**/6**
Auditory	Riddle 4-4-0, turn left at November 3, then contact ground, traffic company Skyhawk 1 mile final	Left Nov 3, contact ground	/1
		Roger	/1
		Callsign	/5
		Total:	**/6**

Appendix E

Participant Instructions

Participant Instructions

Thank you for participating in this study. Please listen the following instructions regarding the contents of this study and required tasks by the participants. If you have any questions please ask one of the researchers now. No questions may be asked during the clearance assessment portion, but you may ask additional questions at the end of the experiment.

Part 1: Informed Consent

After going on these instructions you will be asked to sign an informed consent. Please thoroughly read over the informed consent and ask the researcher(s) any questions you may have before signing the form.

Part 2: Demographics Survey

The demographics survey contains questions regarding general information, language experience, and flight experience. Please fill out all answers to the best of your ability.

Part 3: Language Assessment

The language assessment is a brief 2 part test, containing a listening section and a reading section. The listening section requires you to listen to a 7 minute conversation and answer 10 questions regarding the content of the conversation. The reading section requires you to read and passage and answer 11 questions regarding the contents of the passage. The language test should take approximately 15-20 minutes to complete; however, you have up to 30 minutes to complete the test.

Part 4: Clearance Assessment

Prior to completing the assessment, you will be asked to complete a landing approach using the flight training device. This is intended to familiarize yourself with the controls and the simulator. You will be given a maximum of 10 minutes to complete the approach. After this you will be given 5 minutes to study a sectional chart that corresponds to the clearances you will hear during the assessment. This map is purely for familiarization with the names or airports, vectors, and other locations in the area.

The final portion of the experiment, the clearance portion, requires you to respond to ATC clearances while flying in the flight training device. You will be required to wear a headset during the experiment, through which ATC clearances will be transmitted. All clearances issued will pertain to low altitude flight. The clearances will be presented in addition to radio traffic; therefore, you must listen carefully for your callsign and respond to the clearance when you hear it. Your callsign is Riddle 4-4-0 .In addition, 50% of the clearances will be displayed via text on a secondary monitor within the cockpit; therefore, be careful to monitor this panel during flight. You will be required to readback the entire clearance in the order it was transmitted to you. This includes the transmission of traffic information (i.e. traffic location, speed, and type of aircraft). Please be sure to state your callsign at the beginning of every readback. You will also be given a kneeboard where you can copy down the clearances at your digression.

You will be reminded of these factors before beginning the clearance assessment.

This concludes the instructions for participation in this experiment. Do you have any questions?

Appendix F

Informed Consent Form

Comparison of Voice and Text ATC Communications in the Cockpit for ESL Pilots

Conducted by Shannon Cummings
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Advisor: Dr. Jason Kring
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Embry-Riddle Aeronautical University
Human Factors and Systems
Daytona Beach, Florida 32114

The experiment you are about to participate in assesses the benefits of a mixed modality format (auditory and visual) for ATC clearances. This study will compare the accuracy of the readbacks of a monolingual, English speaking only pilot group to a bilingual, English as a second language pilot group. The experiment will begin with a demographics survey and a brief listening and reading English language assessment. The initial assessments will be followed by a 15 minute training session where you will be allowed to familiarize yourself will the controls of the flight training device and study a sectional of the area that the clearances reference. Following this familiarization period, you will partake in a simulation that will require you to respond to ATC messages; this simulation will take approximately 30 minutes. An attendant will be monitoring your performance, but will not be able to answer questions during the assessment period.

There are no risks associated with this experiment, with the exception of potential mental fatigue. You may choose to terminate your participation at any time during the study. Although we will ask you to fill out a brief demographics questionnaire before we begin the training session, all information provided will remain confidential; your results will remain anonymous. After completing the study, you may receive a copy of your test results as well as a copy of overall participant averages. This information will be distributed upon request only and will not contain any information that will compromise the anonymity of any of the other participants. The session will also be recorded using a hand-held voice recording device. These sound files will be used to score the accuracy of the readback. The sound files will be stored on the principle investigators computer to only be shared with those directly involved in data collection. All sound files will be destroyed upon completion of the research project.

Upon completion of the experiment you will be asked to fill out some paperwork to receive the $20 payment. The information that you fill out on these forms will not be connected to your participation or results. The forms will be sealed in an envelope that will go directly to those dealing with payment and will not be directly viewed by the experimenter. For student employees the $20 will be added to you next pay check. For non-student employees a check will be sent to the address you provide on the payment form within the week following your participation. You may choose to discontinue your participation at any time; however, you will only be paid if you complete the experiment.

Thank you for your participation, please feel free to contact me, Shannon Cummings, or my advisor via the emails provided above regarding any questions pertaining to the study or the results.

Statement of Consent

I acknowledge that my participation in this experiment is entirely voluntary and that I am free to withdraw at any time; however, if I choose to withdraw I recognize that I will not be paid for my participation. I have been informed of the general scientific purposes of this study. I also acknowledge that my results will remain anonymous and if published, my name will not be recognized.

Participant's Name (Print):____
Participant's Signature:____ Date: ____________
Experimenter: ____ Date: ____________

Appendix G

Briefing Script

Briefing

These instructions are to be read before the practice session and assessment period.

Map Session

You will be given up to 5 minutes to study a sectional of the Daytona Beach area. All clearances that you hear will pertain to the Daytona Beach area. This sectional will not be available during flight. I will stop you after 5 minutes; if you do not wish to use the full 5 minutes please let me know when you are ready to continue.

Practice Session

During the practice and assessment portion you will be flying a Cessna 172 with a callsign of Riddle 440. For the practice session, you will then be given 10 minutes to complete a landing approach. The landing approach will begin with you at an altitude of approximately 1,000 feet and a heading of 1-6-5, West of the Daytona Beach Airport.

You will also be listening to clearances at this time. You will hear 4 clearances as you complete your approach, 50% of the clearances will be presented in an auditory format, while 50% of the clearances will be presented in an auditory and visual format on the secondary display. These clearances are not the same clearances that will be used in the assessment, but they do use the same callsign that the assessment does (Riddle 440). The clearances will not pertain to the landing approach but are just to allow you to familiarize yourself with what they will sound like. The clearances will be presented in the presence of radio traffic, so be careful to listen for you callsign and monitor the secondary display. All clearances are pre-recorded; therefore, you will not be able to ask for a repeat nor ask any questions of the controllers.

Before beginning please take time to adjust the seat and familiarize yourself with the location of the controls. You may also request that the experimenter adjust the volume of the transmissions.

Do you have any questions?

Assessment

The assessment portion will begin with the aircraft at an altitude of 1500 ft, West of the Ormond Beach airport with a heading of 2-8-0. You have just completed a missed approach at the Ormond airport and will be flying a runway heading. You are planning to land at the Daytona Beach Airport. You are currently flying under IFR flight rules in VFR conditions.

Throughout the assessment period, you will hear 20 clearances for your callsign, *Riddle 440*. Please respond to the full clearance to the best of your ability; make sure to include your callsign in the readback. All clearances are pre-recorded; therefore, you will not be able to ask for a repeat. If you are unsure, please respond to a clearance to the best of your ability. Please attempt to respond to all 20 clearances.

Half of the clearances will be presented in an auditory format only, while the other half of the clearances will be presented in an auditory and visual format; therefore, make sure you monitor the secondary display during flight as it will be displaying clearances. Clearances will be presented visually while they are being transmitted and will remain on the screen 10 seconds after they are transmitted. You have 10 seconds to respond to all clearances.

Please try to readback all the information given in a clearance. The clearances will provide traffic information, as well as instructions. Please use the instrument panel and flight controls to comply with all ATC instructions (i.e. changes in heading, altitude, airspeed, frequency, etc.). The simulation does not include traffic; therefore, when traffic advisories are transmitted, please try to readback the location of the traffic if you can.

Do you have any questions before you begin? You will not be able to ask questions during the assessment period?