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An Investigation into the Factors that Affect Miscommunication between Pilots and Air Traffic Controllers in Commercial Aviation

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ABSTRACT

Objective: The present research sought to investigate the communication performance of both native English sounding pilots and accented commercial pilots in two different phases of flight, the approach and departure phase of flight.

Background: English language proficiency requirements, standardized phraseology, and readbacks are some of the proactive measures which the aviation industry employs to ensure effective communication. However, despite these efforts, errors in communication still occur, and anecdotal evidence suggests that factors such as language background and phase of flight increase the likelihood of communication errors.

Method: Eighteen hours of air-ground communications at Kingsford Smith International Airport, Sydney, Australia, were analyzed.

Results: The results revealed that accented pilots committed more communication errors than native English sounding pilots and more specifically that these errors were mistakes rather than omissions, and involved words rather than numbers. Communication performance was similar in the approach and departure phases of flight regardless of language background.

Conclusion: These results provide detailed information about the type of communication errors which occur in commercial aviation, their prevalence and the context in which they occur, which helps guide where resources should be directed to further improve safety.

Introduction

Commercial airports are highly complex venues with aircraft taking off and landing in short periods of time, and with ground vehicles moving among taxiing aircraft. Safety depends on accurate communication between these vehicles, and between air traffic controllers (ATC) and pilots. ATC – pilot communication is highly coded, scripted, precise, succinct and unfolds in an expected timeframe (Farris & Molesworth, 2016). This is supported by several mechanisms put in place to minimize communication problems. One of these is a common language, with prescribed phraseology: Aviation English. Yet, aviation communication is not always infallible due to various factors. For instance, despite guidelines regarding speech rate, i.e., no more than 100 words per minute (ICAO, 2016), the sheer volume of communication at major airports often pressures ATC and pilots to speak fast. This is precisely what commonly occurs at John F. Kennedy International Airport, New York in the United States, where air traffic frequencies are heavily congested, and pilots are forced to compete with each other in an attempt to communicate with ATC (Prinzo, Hendrix, & Hendrix, 2009). Accelerated communications is

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one of the causes found to increase the likelihood of miscommunication, especially for non-native speakers of English (Alderson, 2009; Estival & Molesworth, 2016; Molesworth & Estival, 2015; Prinzo et al., 2009).

In most cases, miscommunication is easily identified and resolved by reconfirming the message between interlocutors, which is the standard aviation practice called "readback." However, in rare occasions where miscommunication is not identified and resolved in a timely manner, incidents or accidents can occur (Cushing, 1994; Howard, 2008; Tajima, 2004). One of the best-known miscommunication related accidents is the Avianca Boeing 707 which crashed in part because of a failure by the pilot to declare an emergency using correct phraseology (National Transportation Safety Board, 1991).

With safety being the ultimate objective, such miscommunications must be prevented insofar as possible (Alderson, 2009; Estival, Farris, & Molesworth, 2016). The International Civil Aviation Organization (ICAO) recognized this need and after years of research and consultation with the industry, introduced the Language Proficiency Requirements (LPR) which came into effect in March 2003 (Alderson, 2011). These guidelines place the onus on member states (i.e., aviation governing bodies in signatory countries) to ensure that all flight crew and ATC demonstrate an acceptable level of Aviation English proficiency during international aeronautical communication, regardless of their language background (Alderson, 2009; Barshi & Farris, 2013; Farris, 2016; Tiewtrakul & Fletcher, 2010). The present research aims to examine the efficacy of this requirement in today's real operational environment. Specifically, this study investigates communication errors between ATC and pilots of different language backgrounds, and how contributing factors such as pilot workload, message length, and complexity affect the accuracy of communication in Australia's commercial aviation environment.

In aviation, clear and effective communications are as important as technical skills for flight safety (Tajima, 2004; Wulle & Zerr, 1997). Regardless of their language background, pilots and ATCs share the communicative context (Tajima, 2004). This is a challenging task for most pilots and even more challenging for pilots whose first language is not English, who not only have to learn a new language (i.e., English) but also have to learn the phraseology that is unique to aviation (Estival et al., 2016; Estival & Molesworth, 2012).

The environment in which pilots are required to perform their role further increases the challenge of effective communication. The aircraft cockpit has been described as unpleasant at best and inhospitable at worst (Bor, Field, & Scragg, 2002). Not only is there limited room to move, but it is also noisy, and the noise from aircraft engines has been shown to directly affect communication (Molesworth, Burgess, Gunnell, Löffler, & Venjakob, 2014). Aircraft engine noise can make it difficult for pilots to hear ATC transmissions and can also affect their ability to process and recall the information (Molesworth, Burgess, & Zhou, 2015).

Moreover, pilots are often performing other tasks while communicating. In single pilot operations (i.e., general aviation and some regular public transport operations), pilots are required to "aviate, navigate, communicate," in that order. In contrast, in commercial operations with multiple crew members, these tasks can be divided amongst the crew, with the pilot flying controlling the plane and the non-flying pilot (i.e., pilot monitoring) handling the communications and monitoring the aircraft state. There are however a number of tasks both pilots are required to complete together, such as checklists, and crew members are expected to communicate with each other as well as with ATC (Bonner & Wilson, 2002; Lee & Liu, 2003). Performing multiple tasks is known to increase the drain on an individual's limited cognitive resources, i.e., it is cognitively taxing (Wickens, Lee, Liu, & Becker, 2004), and thus increases the likelihood of error (Ayres, 2001; Hinze, Bunting, & Pellegrino, 2009; Djokic et al., 2010).

Further burden results from the task demands of the different phases of the flight. The approach (including landing) and departure (including take-off) are two of the most critical phases of flight (Bonner & Wilson, 2002; Wilson, 2012; Lee & Liu, 2003; Vidulich & Tsang, 2012), with workload reported to be highest in the approach and landing phase, due to continual monitoring of the aircraft state and the external environment (ATSB, 2017; Bonner & Wilson, 2002; Di Nocera, Camilli, &

Terenzi, 2007; Lee & Liu, 2003; Shorrock, 2005). During the approach and landing phase, pilots must respond to numerous instructions provided by ATC: altitude changes, speed or heading adjustments, approach procedures, and circuit or vector patterns, are just some of the information transmitted to pilots during this critical phase of flight. In the take-off and departure phase, pilots are often afforded the luxury of being able to complete some tasks, such as preparing and configuring the aircraft, while still on the ground, thereby reducing their workload (Bonner & Wilson, 2002; Lee & Liu, 2003; Roscoe & Ellis, 1990; Shorrock, 2005). In contrast, in the approach and landing phase, all tasks must be performed in flight. Even with satisfactory English proficiency, high workload reduces the capacity for pilots to comprehend transmissions from ATC (Orasanu, Davison, & Fischer, 1997; Tajima, 2004).

The number of items in a message, known as information density, has also been found to increase error rate in pilot communications (Boschen & Jones, 2004; Molesworth & Estival, 2015; Prinzo et al., 2009). To mitigate this risk, ICAO provides clear guidelines regarding the complexity of messages transmitted to pilots (ICAO, 2007). While it may seem advantageous from a radio congestion perspective to produce one long transmission instead of numerous shorter transmissions (Prinzo et al., 2009), any advantage may be lost if the transmission, or part of it, has to be repeated.

The present research sought to investigate ATC-pilot communication and more specifically the impact of language background and phase of flight on pilot communication accuracy. The following two hypotheses were proposed, along with one research question.

Hypotheses.

(1) Pilots who are Native English Speakers (NES) will commit fewer communication errors than pilots with English as a second language (EL2).
(2) A positive relationship will exist between complexity of transmission (information density) and communication errors.

Research Question.

(1) Does the phase of flight have an effect on communication errors?

Method

One aim of this study was to investigate the efficacy of communication between ATC and pilots who are either native English speakers (NES) or who have English as a second language (EL2). In this study, pilots' communication efficacy is measured via readback accuracy for any transmission initiated by ATC (i.e., dependent variable). In contrast to previous research carried out in a laboratory (Barshi & Farris, 2013) or flight simulator with set scenarios (Molesworth & Estival, 2015), this study examined communication performance in situ, through a live audio recording of ATC-pilot transmissions. Since and for obvious reasons, it was not possible to query pilots about their native language, the following process was applied to categorize pilots according to their language background. Pilots were classified as "native English sounding" if no foreign accent could be detected and if they were flying with an airline registered in a country where the official language is English (e.g., Australia, New Zealand, the United Kingdom, or the United States of America). Pilots were classified as "accented English" if a non-native English accent could be detected and if the aircraft was registered in a country where English is not one of the official languages (e.g., Japan, Korea, China, Chile). Pilots with an English sounding accent, but who were on an aircraft that was registered in a country where English is not the official language or is one of several official languages (e.g., Hong Kong, Singapore, Malaysia, Fiji) were excluded, as it was less certain whether their native language was English. A random sample (10%) of the recordings were independently verified by a second coder (male Native English Speaker with a Commercial Pilot Licence) to ensure accuracy of the "native English sounding/

accented English" categorization. An inter-rater agreement of 100% was achieved. A total of 132 "accented English" and 141 "native English sounding" pilot transmissions constituted the final dataset.

The data employed was sourced from LiveATC (http://www.liveatc.net), an archive of audio recordings from airports around the world. A total of 18 h from the Tower, Approach and Departure frequencies at Sydney Airport, Australia (ICAO: YSSY) were downloaded. They consisted of 36 blocks of 30 min each, recorded on separate days between 14 February and 29 April 2016, and between the hours of 08:00–10:30 and 21:00–21:30. Air traffic controllers at Sydney Airport, like all ATCs in Australia, are trained and licensed by Airservices Australia, ensuring consistent standards and homogeneous quality of transmissions. There were no differences between the ATCs in the dataset with respect to accent or clarity of delivery.

Since the data for this study was from a country where English is the official language, it was important to ensure, as much as possible, equal representation of native English sounding and accented pilots. Hence, the following method was employed to ensure an unbiased representation. All transmissions between ATC and an accented English pilot (commercial operations only, i.e., excluding General Aviation) were transcribed. Transmissions which were initiated by the pilot were excluded, as were exchanges where ATC asked a question or sought clarification. On average, there were four (4) transmissions from accented pilots (commercial operation) per 30-min block. An equivalent number of native English sounding transmissions were extracted, by choosing the first four (4) such transmissions per recording block. In three cases, due to low traffic, general aviation transmissions, or inaudible transmissions, there were fewer native English sounding transmissions in the 30-min block.

The units of analysis in this study were pairs of transmissions, where the first transmission was initiated by ATC and contained instructions or requests requiring a response from the pilot in the form of a readback (Clark & Schaefer, 1987; Morrow, Rodvold, & Lee, 1994). Miscommunication is defined as "a situation in which a message is not understandable in content, speech (accent), structure, accuracy of readback, or any combination" (Prinzo & Hendrix, 2008). Consistent with Estival and Molesworth (2016), instances of miscommunications were categorized as either omissions or mistakes (incorrect readback); they were further coded for the number of items incorrectly read back or omitted, the type of items involving an error, and the category (number or word) of the erroneous items. An item is defined as a word or phrase (i.e., set of words) which either specifies an action the pilot needs to perform or which contains a piece of information, such as Callsign, Route, Altitude, Frequency, Transponder code, etc., which the pilot must acknowledge, as per the Aeronautical Information Publication (AIP) manual (AirServices Australia, 2014). For instance, the following ATC transmission in (1) contains four items.

(1) "China Southern 325, runway 34 left, cancel STAR, expect independent visual approach."

These items are:
(1) flight callsign ("China Southern 325"),
(2) assigned runway ("runway 34 left"),
(3) approach procedure one ("cancel STAR"), and
(4) approach procedure two ("expect independent visual approach").

The pilot is required to read back those four items. The readback provides confirmation to ATC that the pilot has received and understood the message communicated. In this case, the expected readback would be as in (2).

(2) "34 left, STAR cancelled, independent visual approach, China Southern 325."

All the transmissions that met the predetermined criteria were transcribed, with all items coded as described above. Altering the order of items in a readback was not considered an error. Another typical example of a transmission from ATC is given in (3).

(3) "All Nippon 879, Maintain speed, Turn right heading 170, intercept Runway 16 left."

According to the AIP, the pilot should respond to (3) with the readback shown in (4).

(4) "Turn right heading 170, intercept Runway 16 left, All Nippon 879."

Omitting "Maintain speed" was accepted and coded as correct, while omitting "Turn right" and other deviations from this response were coded as incorrect, as per the AIP (AirServices Australia, 2014).

Which frequency the transmission was recorded from (i.e., Approach, Tower, or Departure) was also noted, thus providing a further classification of errors based on the phase of flight: "Approach," combining data from the Tower and Approach frequencies, and "Departure" from the Departure frequency.

Information density was measured in terms of the number of separate items contained in a single transmission (Cardosi et al., 1996; Prinzo et al., 2009). Like (1), the transmission shown in (3) is composed of four items. The data pertaining to the number of correct and incorrect items were analyzed using Statistical Package for Social Sciences (SPSS) version 22, IBM Corporation.

Results

To investigate whether native English sounding pilots committed fewer communication errors than accented pilots, an independent-samples *t* test was conducted. Using the *t* test for unequal variances because of violations of the assumption of homogeneity of variance, a statistically significant difference was found between native English sounding and accented pilots, $t(215.97) = 2.64$, $p = .009$. As can be seen in Figure 1, the mean number of communication errors per transmission was lower for native English sounding pilots (.0567, SD = .26) than for accented pilots (0.1716, SD = .43), representing a small effect ($r^2 = .03$).

In order to better understand the communication errors committed by pilots, the item type in which the error occurred was examined, as well as the type of error (omission or mistake) and the category of the error (number or word).

Regarding the item type in which the errors occurred, as can be seen in Table 1, the item most commonly omitted by native English sounding pilots was "runway assignment" and for accented pilots, it was both "altitude" and "runway assignment." No statistical analyses were performed at the item level due to the small numbers at this level.

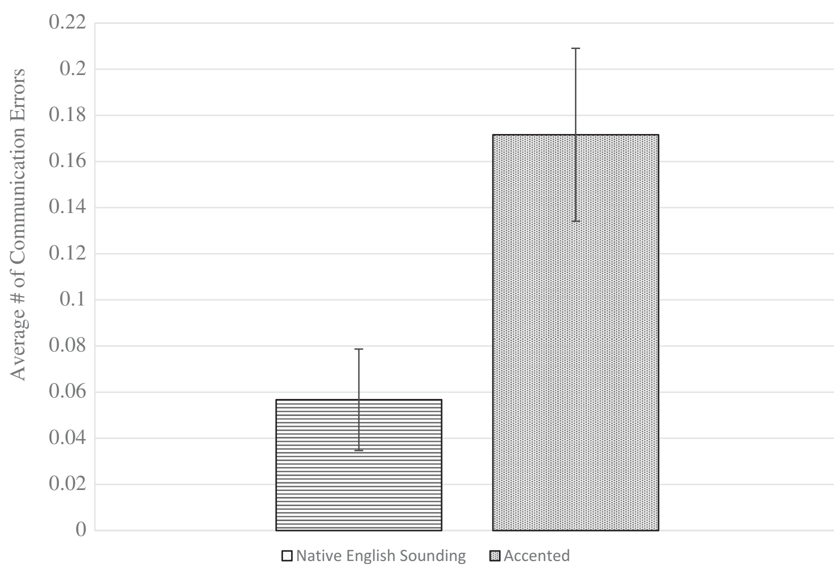

Figure 1. Average number (and standard error) of communication errors committed per transmission by native English sounding pilots and accented pilots.

Table 1. Total number of communication errors committed by native English sounding and accented pilots, distributed across type of error (omission or mistake) and nature of error (number or word).

		Native English sounding pilot			Accented pilot		
		Category of error			Category of error		
Error type	Item type	Numeric	Word	# of errors	Numeric	Word	# of errors
Omissions	Altitude	-	-	0	3	-	3
	Approach type	-	-	0	-	1	1
	Callsign	-	-	0	1	-	1
	Heading	2	1	3	-	-	0
	Radio frequency	-	-	0	1	1	2
	Runway assignment	4	-	4	1	2	3
	Speed restriction	1	-	1		1	1
	Circuit pattern	-	1	1	-	-	0
	Taxi way assignment	-	-	0	1	1	2
	Hazardous report	-	-	0	-	1	1
Total omissions		7	2	9	7	7	14
		Numeric	Word		Numeric	Word	
Mistakes	Altitude	-	-	0	1	1	2
	Heading	-	-	0	2	-	2
	Radio frequency	-	-	0	2	-	2
	Runway assignment	-	-	0	-	1	1
	Taxi way assignment	-	-	0	-	-	0
	Approach type	-	-	0	-	1	1
Total mistakes		-	-	0	5	3	8

Regarding the type of error (omission or mistake), for omissions, on average native English sounding pilots omitted .06 (SD = .26) items per transmission and accented pilots omitted .11 (SD = .36) items, a result that was not statistically significant as indicated by an independent samples t test for unequal variances, $t(241.49) = 1.45$, $p = .149$.

Figure 2 displays the results for mistakes, showing that native English sounding pilots stated all items correctly (i.e., made no mistakes). In contrast, the mean number of items stated incorrectly by accented pilots was .0597 (SD = .24), a result that was statistically significant as indicated by a t test for unequal

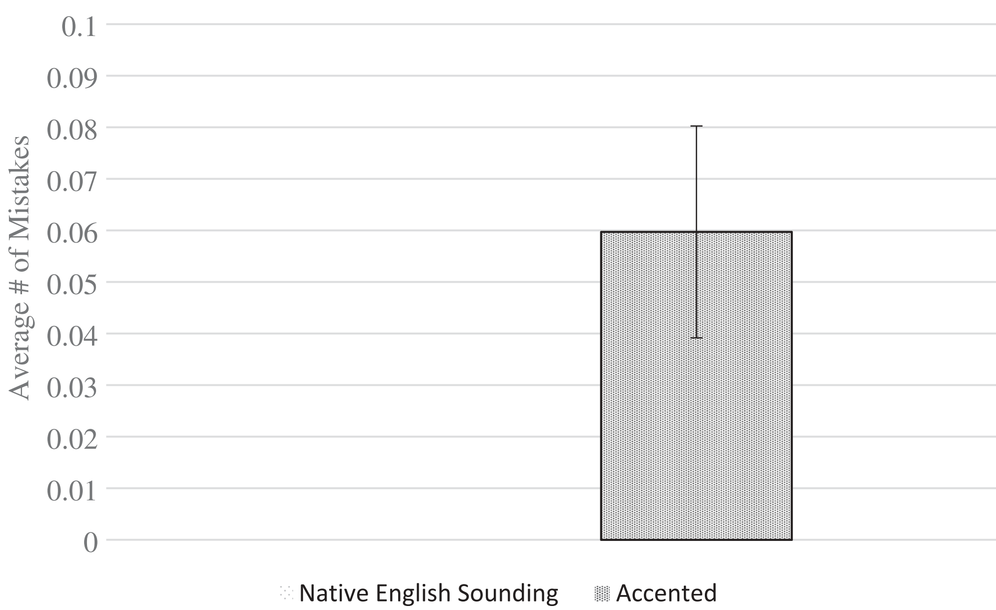

Figure 2. Average number (and standard error) of mistakes per transmission committed by native English sounding pilots and accented pilots.

variances because of violations of the assumptions of homogeneity of variance, $t(133.00) = 2.91$, $p = .004$, representing a small to medium effect ($r^2 = .06$).

Regarding the category of the error (numbers vs words), for numbers, on average native English sounding pilots committed .04 (SD = .20) numerical errors per transmission, while accented pilots committed .10 (SD = .32) numerical errors per transmission, a result that was not statistically significant as indicated by a *t* test for unequal variances because of violations of the assumptions of homogeneity of variance, $t(222.28) = 1.67$, $p = .096$.

For words, as can be seen in Figure 3, on average native English sounding pilots committed .0142 (SD = .12) word errors per transmission, while accented pilots committed .0765 (SD = .26) word errors per transmission, a result that was statistically significant as indicated by a *t* test for unequal variances because of violations of the assumptions of homogeneity of variance, $t(182.67) = 2.43$, $p = .016$. representing a small effect ($r^2 = .03$).

To investigate whether a relationship existed between the number of items in the transmission (information density) and the number of communication errors (error rate), a Pearson's product moment correlation was employed. A weak positive relationship was evident, $r(275) = .200$, $p = .001$. In order to determine if this result was influenced by language background, two separate correlational analyses were performed, one for native English sounding pilots and one for accented pilots. With alpha adjusted to control from family-wise error (Bonferroni adjustment .05/2), the results revealed that indeed language background influenced error rate. No correlation existed between information density and error rate for native English sounding pilots, $r(141) = .160$, $p = .057$, however a weak positive relationship existed between these two variables for accented pilots, $r(134) = .229$, $p = .008$. This result highlights the differences in communication accuracy between native English sounding and accented pilots in the condition of increased information density, a point that is further elaborated on in the discussion.

Finally, in order to determine if communication errors vary as a result of the phase of flight, a further independent-samples *t* test was conducted. With assumptions of normality and homogeneity of variance met, the results failed to reveal a statistically significant difference between the Approach and Departure phases, $t(273) = .373$, $p = .709$. Two subsequent *t* tests, with alpha adjusted to control for family-wise error (Bonferroni adjustment .05/2), failed to reveal a difference between the phase of flight for both native English sounding pilots and accented pilots, largest *t*, $t(132) = .582$, $p = .561$ (accented pilots). Based on this result, communication accuracy was considered to be similar between the two different phases of flight (Approach and Departure) for all pilots.

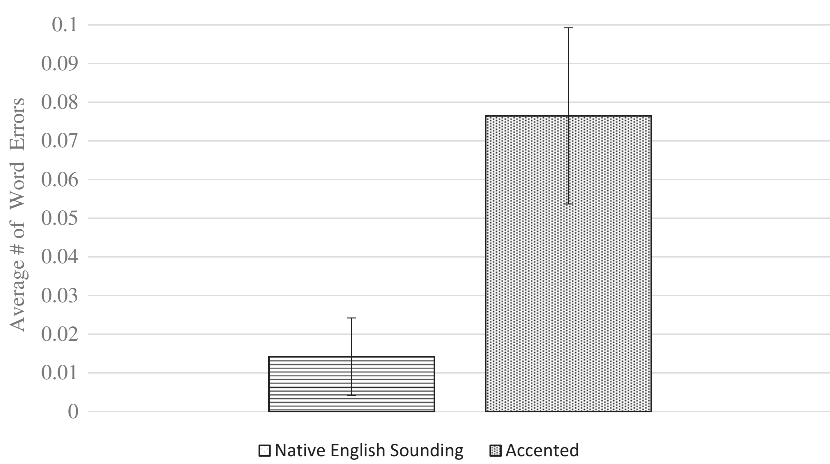

Figure 3. Average number (and standard error) of word errors per transmission committed by native English sounding pilots and accented pilots.

Discussion

The aim of the present study was to investigate miscommunication in aviation, and to examine the impact of language background, workload, and message complexity (i.e., information density) on communication accuracy. The results revealed that both groups of pilots, irrespective of language background, committed communication errors during the readback procedure. Accented pilots, however, committed a greater number of communication errors than native English sounding pilots, a result that supports the first hypothesis. As can be seen in Table 1, the results also revealed differences based on language background for the type of error (omission or mistake). While native English sounding and accented pilots both omitted on average a similar number of items per transmission, accented pilots committed more mistakes than native English sounding pilots; in fact, no native English sounding pilot made a mistake in the current data set.

Regarding the category of error (numeral or word), there were no statistical differences in the error rate between native English sounding pilots and accented pilots for numerical errors. However, there were differences for word errors: native English sounding pilots made fewer word errors than accented pilots.

The fact that both groups of pilots make errors in their transmissions highlights the ongoing challenge of effective communication in aviation. For native English sounding pilots, since they committed omissions rather than mistakes, the challenges seem to be those of remembering (or learning and recalling) what items must be read back, or adhering to the protocol. The reason why such omissions occurred remains unknown but could include: workload, time pressure, or being indifferent to protocol. For EL2 pilots, who committed both omissions and mistakes, the challenges seem to involve both remembering which items must be read back and ensuring accurate readback. Whether the reasons why such errors occurred are similar for both groups is an area for future research.

The results, however, indicate that EL2 pilots need to obtain a greater command of aviation phraseology, as they committed more word errors (as opposed to number errors) than native English sounding pilots. This new finding has important implications for aviation communication training. The choice of lexical items in aviation is constrained by the phraseology, in contrast to numbers where the possible range is very large. Knowing that improvements in aviation communication can be obtained by improving pilots' mastery of the phraseology allows for a targeted approach.

The second hypothesis predicted a relationship between message complexity (information density) and communication errors. The results provide support for this hypothesis but are more nuanced than hypothesized. There is an interplay between message complexity, communication error, and language background. As the number of items in the transmission increased, so did the error rate, but only for accented pilots. While this result is important, and is supported by a growing body of literature that illustrates differences between native and non-native speakers in terms of communication performance (Mayo, Hansberry, & Buus, 1997; Scharenborg, Coumans, & van Hout, 2018) and the differing effect of stressors such as noise on effective communication according to language background (Jang, Molesworth, Burgess, & Estival, 2014; Molesworth et al., 2014), it needs to be interpreted within the confines of the research. Message complexity (i.e., number of items per transmission) in this dataset was not infinite: the most complex message had eight items. Nonetheless, these results confirm the differences in the impact of message complexity on the two groups. The results also highlight the importance of adhering to the ICAO's recommendation of transmitting no more than three items in each communication exchange (Barshi, 1997).

In relation to the research question which sought to determine whether the phase of flight (i.e., approach vs departure) had an effect on communication errors, no differences were evident in the current data set. Assuming that the landing phase of flight presents a higher level of workload for pilots than the departure phase (ATSB, 2017; Bonner & Wilson, 2002; Lee & Liu, 2003; Roscoe & Ellis, 1990; Shorrock, 2005), at face value this particular increase in workload does not seem to adversely impact communication accuracy (Mosier et al., 2013). This result is in direct contrast to Prinzo (2008), who found that pilots committed more communication errors during the approach phase compared to other phases of flight. Estival and Molesworth (2016) had also found a correlation between workload and communication errors in general aviation. It is possible that the differences in terms of workload between the two phases of flight in the current study were not sufficient to induce errors. This may be because of the way pilots manage tasks on the flight deck, giving higher priority to communication during the approach phase than would be apparent during the departure phase, hence effectively controlling for communication errors. As discussed in the introduction, radio communication is generally the responsibility of the pilot monitoring, not of the pilot flying. If communication was the responsibility of the pilot flying (as it usually is in general aviation), it is likely that an increase in communication errors would result, thus possibly reflecting more closely the results of Estival and Molesworth (2016) for general aviation. This, however, requires future research.

It is also possible that the proactive measures employed in commercial aviation have minimized or even eliminated the differences between the two phases of flight. Airlines around the world have proactively introduced the concept of a sterile cockpit. Below a predefined altitude, in many cases 10,000 feet, all communication exchanges are limited to flight operations. Pilots are provided with information about their destination airport, such as weather and runway direction, through an automated recording known as the Automatic Terminal Information Service (ATIS). Having this information allows pilots to plan ahead, potentially reducing their cognitive load, through the minimization of new information. In addition, using text form communication such as controller-pilot data link communications (CPDLC) also significantly relieves radio frequency congestion (Hah, Willems, & Schulz, 2010). How the sterile cockpit requirement and automated information service impact on communication accuracy remains an area for future research.

The results presented above need to be interpreted within the confines of the study, as the method used to collect the data (recordings from a third party) does not make it possible to query the individual pilots' language background or aeronautical experience. What is known, however, is that the pilots in the dataset held an ATPL (Air Transport Pilot Licence) if captains or at least a CPL (Commercial Pilot Licence) if first officers, all with experience in international operations. In addition, the method used to categorize "native English sounding" and "accented pilots" ensures that only clear cases were included in the dataset, as marginal cases were excluded. Thus, the results provide a sound basis for generalization. While the dataset covered a large number of hours of pilot-ATC communication, the number of errors in the transmissions was limited. This is a positive finding but presents challenges for statistical analyses. Future research will consider expanding the number of hours examined. For this study, implications are only presented for significant results. It may well be that other significant results will be found with a larger dataset.

Conclusion

Error-free communication in aviation remains an elusive goal. While the results of the present research confirm earlier studies showing that Native English pilots are not immune from communication errors (Alderson, 2009; Nevile & Walker, 2005), they also show that, as also suggested by those studies, accented pilots tend to be more challenged by Aviation English. The results from this study show that they make more overall errors in their transmissions than native English sounding pilots, but also that the type of error they make is different: accented pilots made mistakes, while native English sounding pilots only made omissions, and accented pilots made more errors with words than native English sounding pilots, while both groups made similar numbers of numerical errors. Phase of flight, and the reported higher levels of workload during the approach and landing phase, did not trigger a higher number of errors compared to the departure phase. Both of these are new results which should aid in improving communication in commercial aviation.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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