Use the right words - An observational study over the association between communication skills and errors of aircraft pilots.

Bachelor Thesis

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Abstract

Introduction: Communication can cause huge problems for professional teams that are working in safety critical environments, e.g. aircraft cockpits. They have to fulfill different tasks and to communicate effectively at the same time. Research findings show that problems related to communication can be found in 70-80% of all accidents in aviation. Additional research results show that the use of certain communication elements correlates negatively and significantly with the number of pilot failures. It is supposed that bad communication skills will increase workload, or lead to a mismatch between the (shared) mental model of the cockpit crew and the real world, or activate a wrong mental schema. This study tested if there do exist statistical correlations and associations between certain communication elements and the different types of errors, aircraft pilots make. Those correlations were assumed to be significant.

Method: An observation form and an error protocol were developed and were used during 23 check flights in a Flight Training Center. Correlations between the different variables was calculated and afterwards a stepwise multiple regression analysis was used to construct the best models in describing the associations between communication skills and pilot errors.

Conclusion: According to the assumption of this study, significant correlations between different communication elements and different types of errors were found. Furthermore, four models that describe the association between communication skills and the total number of errors, skill-based errors, decision-based errors and perceptual errors were constructed.

Discussion: The aim of this study was to investigate if there do exist statistical correlations between different types of pilot errors and different communication elements. Further, this study constructed four models that are best in describing the association between communication skills and the different types of pilot error. Significant correlations between different communication elements and different types of pilot errors were found. The strongest limitations of this study is the limited sample size and the statistical analysis that could have eliminated communication elements, which are better in describing the association between pilot errors and communication skills. Random variation in the data can cause this problem. The study can finally conclude that there do exist strong associations between communication skills and errors and that further research is necessary to investigate this phenomenon.

Samenvatting

Inleiding: Communicatie kan voor professionele teams die in een complexe werkomgeving (bijvoorbeeld vliegtuig cockpit) werken grote problemen opleveren. De teams moeten verschillende taken vervullen en tegelijkertijd effectief met elkaar communiceren. Uit wetenschappelijk onderzoek blijkt dat er in 70-80% van alle vliegtuigongelukken problemen te vinden zijn die met communicatie te maken hebben. Verder zijn er verschillende correlaties tussen bepaalde communicatie elementen en fouten door piloten gevonden. Er wordt vermoed dat ineffectieve communicatie de werkbelasting verhoogt, naar een verkeerd *(shared) mental model* voert of een verkeerd *mental schema* activeert. In deze studie wordt er onderzocht of er significante correlaties te vinden zijn tussen de verschillende communicatie elementen en verschillenden soorten fouten. Er wordt verwacht dat bepaalde communicatie elementen met bepaalde soorten fouten correleren.

Methode: Er zijn twee observatieprotocollen ontwikkeld, een voor communicatie vaardigheden en een voor fouten door piloten. Deze observatieprotocollen werden gebruikt tijdens 23 trainingsvluchten in een vliegtrainingscentrum. Aansluitend werden er correlaties berekend tussen de verschillende variables en werd er een *stepwise multiple regression* analysis uitgevoerd.

Conclusie: Er werden significante correlaties gevonden tussen verschillende communicatie elementen en verschillende soorten fouten door piloten. Verder werden er vier modellen ontworpen die de associaties tussen communicatievaardigheden en de verschillende typen fouten het best beschrijven.

Discussie: Het doel van dit studie was te onderzoeken of bepaalde communicatie elementen correleren met het aantal fouten door piloten en nagaan welke communicatie elementen het meest geschikt zijn om deze associaties te beschrijven. Er zijn verschillende correlaties gevonden. De resultaten werden ondersteund door verscheidene andere onderzoeken, echter zijn er ook tegenstrijdigheden gevonden. De grootste beperkingen binnen dit onderzoek waren de grootte van de steekproef en de gebruikte statistische methode. Doordat er een kleine steekproef was, kan het zijn dat extreme scores de resultaten beïnvloed hebben. Daarnaast kan het zo zijn dat de *stepwise multiple regression* analysis bepaalde communicatie elementen uit het model heeft verwijderd die er eigenlijk in horen. Uit het onderzoek kan worden geconcludeerd dat er associaties bestaan tussen bepaalde communicatie elementen en bepaalde typen fouten. Er is meer onderzoek nodig om deze associaties te kunnen verklaren.

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Table of Contents

"Around ten years ago I was flying from Istanbul to China. During the take off, the flight and the landing everything was all right and we had no problems. When we arrived at our parking position my First Officer communicated with the ground engineer. We are using standardized non-verbal signs to communicate with the ground engineers because of the noise at the airports and the limited English level of some ground engineers. My First officer was very young and stressed because it was one of his first long distance flights. When he was communicating with the ground engineer he totally misinterpreted the non-verbal signs of the engineer and told me that we had to release the breaks instead of holding them. The result was that we were rolling uncontrollable a few meters backwards. We were lucky that nothing happened, but if there would have been a car or another ground engineer behind the aircraft, this failure had really big consequences. This example shows me that pilots have to get trained and evaluated in their communication skills."

One Airline Captain, 2013

Introduction

As it is defined by the Oxford dictionary, communication is "*the imparting or exchanging of information by speaking, writing, or using some other medium*". In their research Dohen, Schwartz and Bailly (2010) showed that interpersonal or face-to-face communication is highly influenced by the situation and the environment in which people communicate with one another. The response time of people who are communicating with someone else while dealing with another task is significantly higher than the response time of people who only concentrate on the conversation (Whitehead, Schiavetti, Whitehead, & Metz, 1997). As a consequence, environmental and situational effects on communication can cause huge problems for professional teams that are working in safety critical environments (e.g. the cockpit of an aircraft). Special environments like these require concentration on the main task and effective communication simultaneously. This makes teams that are working in these environments highly fragile for breakdowns in their communication and/or influences their task performance negatively (Hu, Arriaga, Peyre, Corso, Roth, & Greenberg, 2012).

Communication in the Cockpit

In general, communication in the cockpit is divided into intra-cockpit communication and/or inter-cockpit communication (U.S. Department of Transportation, 2001). The intra-cockpit communication includes the communication between the two pilots and the communication between the pilots and the interfaces/applications of the aircraft (Chen et al. 2012). The inter-cockpit communication includes the communication between cockpit crew and cabin crew (Chute, 1995), the communication between cockpit crew and air traffic control (ATC), and the communication between cockpit crew and ground staff (U.S. Department of Transportation, 2001). According to a study of the NASA Aviation Safety Reporting System (ASRS), discussed in a research paper written by Sexton and Helmreich (2000) and the Airbus Flight Operations Briefing Notes (2004), problems related to intra-cockpit and/or inter-cockpit communication are found in 70-80% of all accidents in aviation. Sexton and Helmreich (2000) tested whether the language use of cockpit crews has influence on the number of errors that captains and/or the first officers make. They measured the use of different communication elements and compared them with the flight performance of the first officers and the captains. Results show that the use of short words (less than six letters) and the first person plural (we) correlates negatively with pilot failures. According to their interpretation of this correlation, the communication improves with the use of short words. Through the improved communication pilots can benefit from more mental resources to fulfill other tasks. They further argue that the use of the first person plural (we) creates a team spirit in which crew members can communicate more freely with one another.

Furthermore, a good team spirit is necessary for an effective communication between cockpit crew and cabin crew. Primary influential factors of the communication between these two crews are hierarchical differences and out-group behavior (Chute, 1995; Chute, 1996). The first reason for these factors is the little contact between the cockpit crew and the cabin crew because they work in two different departments. Second, the cabin crew members are at the lower end of the hierarchical system in aircrafts. This might lead to a perceived barrier with the consequence of avoiding to speak with the captain or first officer. The result is an absence of communication (Chute, 1995). In turn, this absence of communication has already led to a number of incidents in aviation (Chute, 1996).

Next to the cockpit crew and the cabin crew, the air traffic control (ATC) is the third human party, which is very important for the safety of a flight. In their Flight Operations Briefing Notes (2004), Airbus discusses the communication between the cockpit crew and the ATC controller. In order to prevent a lack of communication, which might influence flight outcomes negatively, pilots (cockpit crew) and controllers (ATC) have shared responsibilities. Furthermore, to prevent a misunderstanding between pilots and controllers, a confirmation/correction process is implemented into their standard operational procedures. Airbus describes this as a communication loop (see Figure 1).

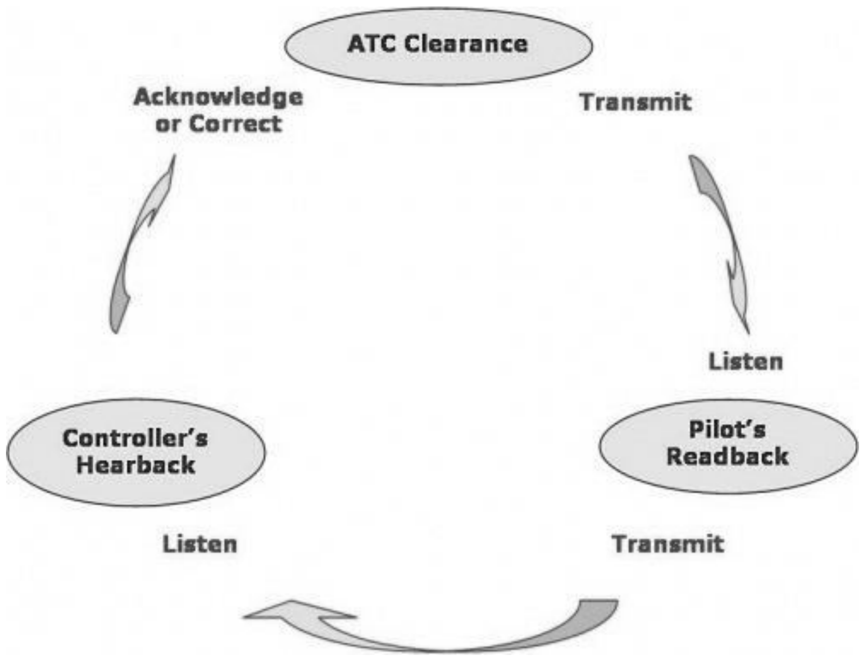

Figure 1 The Pilot/ Controller Communication Loop

In spite of this confirmation/correction process "Readback" and "Hearback" errors occur (U.S. Department of Transportation, 1998). In order to obviate such communication errors, the International Civil Aviation Organization (ICAO) defined a couple of communication rules for the pilots. Firstly, pilots need to enunciate words clearly and distinctly, need to stay at an even level of speech rate/volume and need to use standard phraseology while communicating with the ATC or one another (ICAO, 2013). The use of these communication elements should make the communication easier and more comprehensive. In return this should save time and effort, which pilots can use for other tasks. Moreover, the use of these communication elements is supposed to help pilots to build up a shared mental model of their environment (Airbus, 2004).

The importance of mental models

Pilots need mental models to communicate with the aircraft and also to work effectively as a team. The communication between the pilots and the aircraft is a highly complex task for the pilots. Besides their other tasks, pilots have to observe and interpret multiple aircraft output-systems and furthermore adjust them if necessary. In order to fulfill these complex tasks pilots are using mental models, which are internal representations of their external environment including function, interaction and construction of the aircraft. To update their mental models pilots use variables from the real world, which are according to their experience valid and reliable in presenting the current state of the aircraft (Baxter, Besnard, & Dominic, 2007). Without these mental models, pilots would not be able to handle all the information they receive from the aircraft displays (Moray, 1996). A problem of these mental models is that they only represent an interpretation of the world, but this is not always the current state of the real world (Boy, 1987). If one of the aircraft systems fails, while it functions correctly according to the perception of the pilots, this could lead to a mismatch between the real world and the internal representation of the pilots. In this case, the pilots would overtrust the outcomes of the aircraft displays, which could lead to wrong or poor decisions and influence flight outcomes negatively (Pritchett, Balazs, & Edwards, 2002).

Shared mental models between cockpit crew members are important for an effective decision-making process (Orasanu, 2010; Reynolds, Blickensderfer, 2009). In order to make the right decisions during an emergency situation, cockpit crews need to share their environmental perception (U.S. Department of Transportation, 1992). This shared perception should include the source of the problem, as well as the possible actions the crew can take and furthermore the current state of the aircraft. To create these shared mental models cockpit crews have to communicate effectively over executed procedures and changes of the aircraft. Furthermore, it is important that the pilots communicate in a simple way with one another, as it would otherwise increase the workload of the pilots (Orasanu, 2010). To challenge these problems airlines implemented standard call-outs. These standard call-outs are predefined phraseologies that all airline pilots have to know. The use of these standard phraseologies is supposed to make the communication more automatic and prevent misunderstandings between pilots from different countries or with different dialects. Standard call-outs and especially Flight Mode Annunciator (FMA) call-outs are normally used to inform the second pilot about executed procedures and changes of the aircraft. This should reduce decision-based errors by updating the shared mental model of the cockpit crew (Airbus, 2004).

The Perceptual Cycle Model

Because of the number of failures in interpretation, Plant and Stanton (2012) discussed those failures in terms of the perceptual cycle model (see Figure 2). According to this model, discussed in the paper from Plant and Stanton (2012), pilots create an internal representation of their external environment, which is called schema of environment.

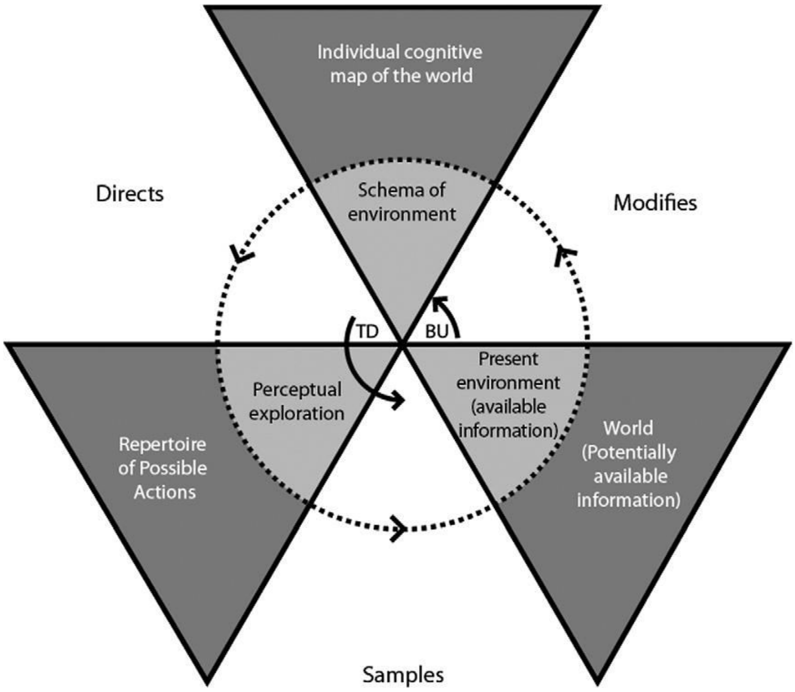

Figure 2 Perceptual Cycle Model

This schema is created based upon prior experiences. Pilots can have different schemas for different situations. In order to activate these schemas pilots use information out of the real world, compare them with prior experiences and activate the schema for the current situation. A mismatch between the schema and the real world could arise if pilots interpret the variables of the real world incorrect and activate a wrong schema. This would influence their decision-making process negatively (Orasanu, 2010).

In their paper Plant and Stanton (2012) use the Perceptual Cycle model to investigate the influence of mental representation on aircraft accidents. The authors are using the Kegworth disaster as an example, in which the pilots made a false decision based on their prior experiences. The pilots received the message from their board computer that smoke entered the cabin. They were faced with this problem a couple of times in the past, because problems with engine two (right side of the aircraft) caused this similar problem over years in old aircrafts. The pilots knew that this problem could occur because of other reasons but based on their prior experience they did not discuss this option. The true reason was a problem in engine one (left side of the aircraft), which is why smoke entered the cabin for only a short time. After the pilots shut down engine two no more smoke from engine one entered the cabin. The pilots thought that they made the right decision. A couple of minutes later engine one failed and the aircraft crashed without one of the engines working before reaching the airport. Over 70 passengers died (Department of Transportation, 1990). This specific problem in relation to mental representation was added by Plant and Stanton (2012) to the Perceptual Cycle model, see Figure 3.

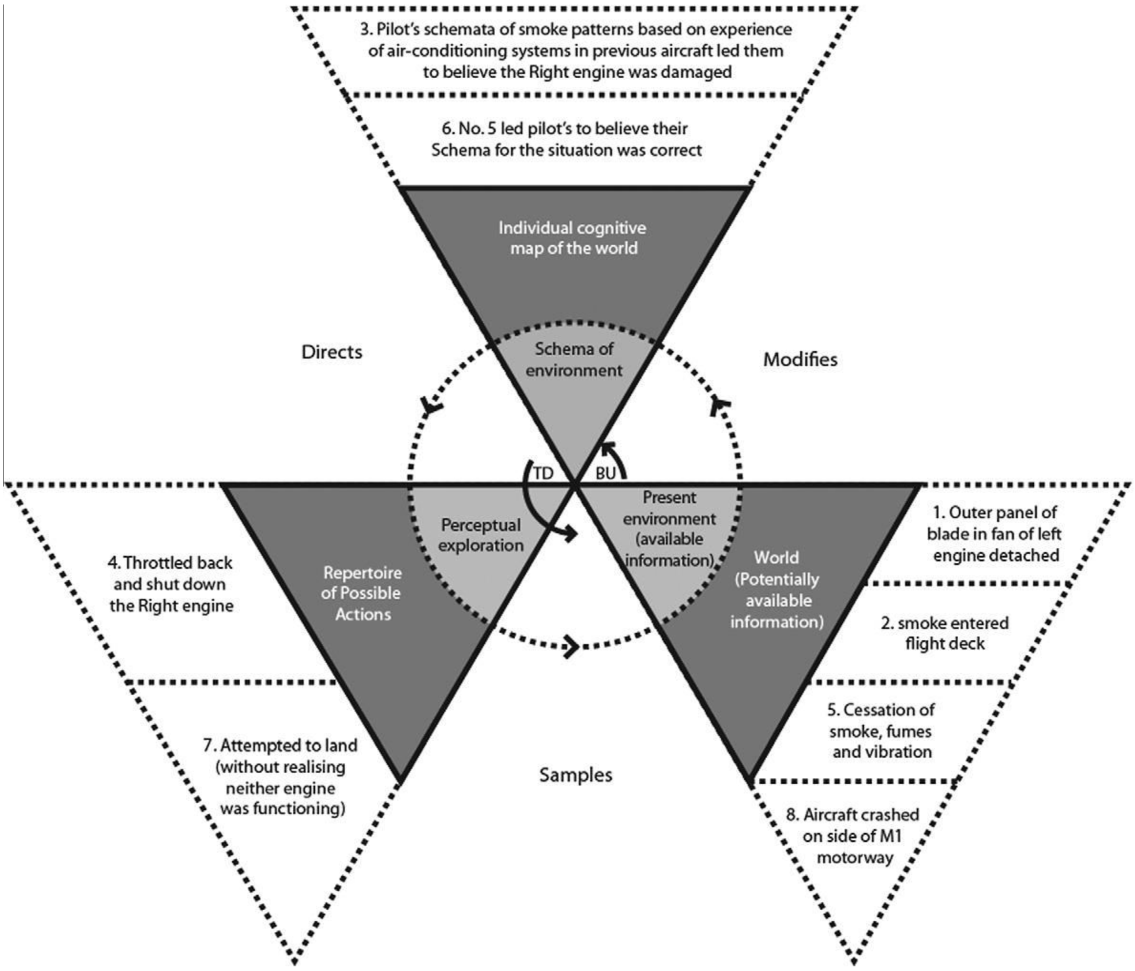

Figure 3 Perceptual Cycle Model with added information

Workload and limited mental resources

As mentioned in the introduction of this paper, pilots have to split their mental capacity in order to fulfill different kinds of tasks like communicating with other persons, maintaining situational awareness or navigating the aircraft in the sky. These multiple tasks can lead to an extreme workload of the pilot when he is confronted with dangerous or abnormal situations, e.g. flying through a storm (Wickens, Lee & Becker, 2004). The term workload can be described as the ratio of:

Time required (to perform tasks) / time available.

A ratio bigger than 1 indicates that an "overload" occurred, with the result that the performance of, at least one, task would decrease. It is important to note that different tasks are using different cognitive resources (Wickens, 2002). This means that some tasks, which use different mental resources like a perceptual task and an auditory task, can be performed better at the same time than tasks, which are using the same mental resources like two perceptual tasks. Furthermore, it is important to note that dealing with two tasks at the same time, even if they use most of the time different cognitive resources, will have a negative effect at least at a certain level. The reason is that some cognitive resources, like the working memory, are not shareable (Wickens, 2008).

The limited cognitive resources might be enough to manage multiple tasks during a normal flight. If the flight situation gets more complicated, however, it is more difficult for the pilot to fulfill all tasks simultaneously because he needs more mental resources for each task. This in turn can influence his other task, e.g. the flight performance, negatively (Kahneman, Ben-Ishai & Lotman, 1973). This influence depends on the skill level of the person. It is possible for some people to manage different task even if they become more complicated. The requirements are that the pilots are well educated and familiar with their tasks, e.g. how to communicate effectively (Navon & Gopher, 1979).

Pilot errors

The distinction between different types of pilot errors is very important because pilot errors can have different sources. Errors are unintended and represent failures that human operators do while they are trying to reach a goal (Reason, 1990).

The Human Factors Classification system classifies pilot errors into three subcategories. First skill-based errors, second decision-based errors and third perceptual errors. Skill-based errors are being described as errors in basic flight skills. Pilots are well trained in these flight skills and have not to think too much about them. In return, skill-based errors occur because of attention or memory errors. Decision-based errors are simply described as taking the false action. They could have different sources that lead to poor or wrong decision making. Perceptual errors are being described as a difference in the perception of the pilots and the reality, such as disorientations or visual illusions (U.S. Department of Transportation, 2000).

Crew Resource Management

In order to prevent negative flight outcomes caused by interpersonal or cognitive errors, airlines implemented a special training program called Crew Resource Management (**CRM**). In this program, pilots and cabin crews are being trained in interpersonal and cognitive disciplines (Civil Aviation Authority, 2006). This training was implemented in the beginning of the 1980`s, after the importance of interpersonal and cognitive aspects was perceived for the first time. This training has been developed over the years and different components like the line-oriented flight training (**LOFT**) were added (Helmreich, Merritt, & Wilhelm, 1999).

During the LOFT cockpit crews simulate scenarios like an emergency landing or even a full mission like a whole flight from one destination to another. An instructor is able to create some special events for the pilots, who in turn have to react immediately, fast and correct. Most of the special events are related to communication, leadership or management (Civil Aviation Authority, 2006). The instructors are using the NOTECHS (non-technical skills) system to debrief pilots after their training. The NOTECHS system includes four different categories: Co-Operation, Leadership and Managerial Skills, Situation Awareness and Decision Making with different behavioral markers (see Table 1) and was developed in a pan-European project in the mid 1990's, in order to have a general system for evaluating pilots after their training.

Table 1

NOTHECH categories, subcategories and examples of behavioral markers

Category	Subcategory	Behavioral markers (examples)
Co-Operation	•Team-building and Maintaining	**Good:** Polite and friendly approach **Bad:** Ignoring inputs
	•Considering of others	**Good:** Showing interest **Bad:** Forcing opinions
	•Supporting others	**Good:** Offering solutions to problems **Bad:** Not fulfilling promises
	•Conflict solving	**Good:** Being good listener **Bad**: Taking sides
Leadership	•Use of Authority and Assertiveness	**Good:** Supporting and ensuring task completion **Bad:** Being too nice
	•Planning and Coordination	**Good:** Interactive briefing/discussion of salient points **Bad:** Focusing on irrelevant tasks
	•Providing & Maintaining standards	**Good:** Following SOP's/correct use of checklist **Bad:** Over reliance in others
	•Workload Management	**Good:** Prioritizing on primary tasks **Bad:** Briefing at wrong time
Decision Making	•Problem Definition/Diagnoses	**Good:** Asking relevant questions **Bad:** Ignoring inputs from others
	•Risk assessment / Option choice	**Good:** Discussing risks with others **Bad:** Misinterpreting Data
	•Option Generation	**Good:** Listening to others options first **Bad:** Ignoring other inputs
	•Outcome Review	**Good:** Making time to review **Bad:** No review
Situation Awareness	•Awareness of Aircraft Status	**Good:** Speaking up when unsure **Bad:** Misinterpreting data
	•Awareness of Time	**Good**: Timely preparation and briefings **Bad:** Exceeding time limits
	•Awareness of Environment	**Good:** Monitoring raw data/charts **Bad:** Over-reliance on single data source

The category "communication skills" is, in spite of the importance of communication in air traffic, not part of the NOTECHS. Behavioral markers, which refer to communication, however, can be found in every single category (Flin et al., 1995).

Present study

The present study expands the idea to use pilots' use of language as an indicator for flight outcomes. As mentioned in the introduction, some communication elements are negatively correlated with pilot failures (Sexton & Helmreich, 2000), other are probably able to increase the workload of the pilots (Wickens, Lee & Becker, 2004), or lead to a mismatch between the (shared) mental models and the real world (Airbus, 2004), or activate wrong schemas (Plant and Stanton, 2012). It will be tested whether the use of the first person plural (we) is able to predict the total number of pilot errors, as discussed by Sexton and Helmreich (2000). The observational study from Sexton and Helmreich (2000) was conducted with the old cockpit crew setup including Captain, First Officer and Flight Engineer. Sexton and Helmreich (2000) discussed this as a main limitation of their study because the hierarchical structures from a cockpit with two pilots and one engineer cannot be compared with the new setup, which includes only two pilots.

This study will further test if the communication elements from Table 2, which were conducted in an unpublished pretest, are able to predict the number of pilot errors and if it is necessary to use all of them. This pretest was an interview study with subject matter experts, concerning the influence of communication elements on pilot's flight performance.

Table 2

Communication elements from the pretest that will be tested in this study

Using simple sentences
Using standard call-outs
Using FMA call-outs
Using short words
Using all available information sources
Having a consistent speech rate
Using the first person plural (we)
Enunciating each word clearly and distinctly
Having constant speak volume
Making correct Readbacks

In predicting pilot errors or one type of pilot errors, the validity of some items can be better than the validity of other items. It would be unnecessary to include those variables that add no further information. Items with a high validity in predicting pilot errors could also increase the validity of the NOTECH system. The NOTECH includes non-technical skills of pilots that should decrease the danger of pilot errors. As communication skills are non-technical skills, a communication element that is able to predict pilot errors would increase the validity of the NOTECH system. The current study uses observations to measure the relationship between communication and flight performance. Other studies e.g. Plant and Stanton (2012) or Chute (1996) used aircraft accidents to investigate whether communication errors have caused these accidents. In contrast to the study of Sexton and Helmreich (2000) the crew size, in the current study, is different and cockpit crew behavior was measured in contrast to single pilot behavior. The current study wants to investigate in how far associations between communication skills and flight performance exist and whether these associations give evidence for the recent, more theoretical work, and whether the old results from Sexton and Helmreich (2000) are generalizable to the new cockpit crew setup.

Expectations

This study expects cockpit crews with good communication skills, as defined by the communication elements from table 2, will make fewer errors than cockpit crews with bad communication skills. Therefore, a negative correlation between the total number of errors and the use of the communication elements from table 2 is expected.

Skill-based errors

It is expected to find negative correlations between the use of the communication elements (using simple vocabulary, using short words, keeping a consistent speech rate, enunciating each word clearly and distinctly, having constant speak volume, using correct Readbacks) and the number of skill-based errors. These correlations are expected because the use of these communication elements should make the communication more comprehensible (ICAO, 2013) and should therefore decrease the workload of the pilots (Wickens, Lee & Becker, 2004). If the communication becomes too difficult and the communication task needs too much time an “overload” can occur (Wickens, 2002; Wickens, 2008). In this case pilots would not be able to focus their attention on their basic tasks (Wickens, Lee & Becker, 2004).

Decision-based errors

Furthermore, negative correlations between the number of decision-based errors and the use of the communication elements (using first person plural (we), using standard call-outs, using FMA call-outs and using all available sources to get information) is expected. The communication element (using the first person plural) should create a team spirit. This team spirit should make it easier for the pilots to speak with one another over problems (Sexton & Helmreich, 2000). This would increase their efficacy to make the right decisions. The standard and FMA call-outs are necessary to maintain situation awareness and to build up shared mental models between the pilots (Airbus, 2004). Shared mental models, between two pilots are necessary for a good decision-making process, especially in emergency situations as described by Orasanu (2010). As discussed in the introduction, the communication element (pilots use all available sources to get information) should decrease the risks of a mismatch between the (shared) mental model of the pilots and the current state of the aircraft. This mismatch would lead to an increase of poor or wrong decision making. Furthermore, it is necessary for pilots that they use all available sources to receive information in order to prevent the activation of a wrong schema that would influence the decision-making process negatively (Plant and Stanton, 2012).

Perceptual Errors

It is expected to find negative correlations between the number of perceptual errors and all ten communication elements. It is further expected that this correlations are less strong than the correlations between the communication elements and the other two types of errors. This is expected because perceptual and auditory tasks are, most oft the time, fulfilled in different brain areas and need for those reason less of the same mental resources (Wickens, 2002; Wickens, 2008). The offspring of perceptual errors are not only misperceptions. Bottom-up processes (expectations) can influence the perception of the pilots especially when pilots flying in the dark or in bad weather and did not have the chance to use cues from the real world. To obtain this kind of errors a good communication over the current state of the aircraft is necessary (U.S. Department of Transportation, 2000).

Method

Participants

One German, one Irish and two Turkish flight instructors have conducted the observational study. The four instructors have the rank captain and have finished an education as flight instructor for civil aviation.

12 airline pilots with the rank captain and 12 airline pilots with the rank first officer participated in this observational study. All 24 airline pilots were recruited by the flight instructors in a Flight Training Center from Turkish Airlines in Istanbul. All participants signed the informed consent form and the ethics committee of the University of Twente approved the study.

Setting and materials

The observational study was conducted in two different flight simulators in a simulator of an Airbus 320 and in a simulator of an Airbus 330. The simulators are build like real aircraft cockpits, including all functions and reactions of a real plane. The simulators are further able to simulate sound, smell, movements and in some degree physical forces of a real aircraft. During the flight session a regular cockpit crew with two pilots, a flying and a non-flying pilot, were observed. The observer sat behind them. Further, the instructor used a headset to hear the conversation between the two pilots. Figure 4 shows the interior of a flight simulator, with the workplace of the pilots (1) and the workplace of the instructor (2).

Figure 4 Interior of a flight simulator from an Airbus 320

In order to measure the communication skills of the pilots, an observation form has been developed. The communication elements in this observation form have been created based upon an unpublished pretest. The observation form includes ten communication elements that are, according to the results of the pretest, indicators for a good use of language (see Table 2). The pretest was a semi-structured interview study with ten subject matter experts. There answers get compared and communication elements that were named over the average get used to develop this tool. Examples of these communication elements are “pilots use the first person plural (we) while communicating with each other” or “pilots keep a constant speech volume if they speak more than 5 seconds”. Next to the good communication elements, which influence the communication positively, the observation form includes the opposite of the positive statements, which therefore influence the communication negatively. Examples are “ pilots use the first person singular (I) or the second person singular/plural (you) or “pilots change their speech volume if they speak more than 5 seconds”. The observers marked the frequency of how often these behaviors occurred on the observation form. The full observation form can be found in Appendix A.

In order to measure the error rate of the pilots, the observers used an error protocol. The observers marked the number of skill-based, decision-based and perceptual errors on this protocol. These errors have been classified by the Human Factors Analysis and Classification system (U.S. Department of Transportation, 2000). The Error protocol can be found in Appendix B.

All observations were conducted during a check flight. Check flights are standardized training sessions, which pilots have to do every six months. In these check flights, pilots fly their aircraft from one destination to another while they get confronted with abnormal flight situations. The duration time of one flight is 2 hours, excluding briefings and preparations before the flight. During this observational study, each pilot got confronted with almost the same abnormal situations. For example, every session contained an engine failure during a take off. After the two pilots arrived at their destination, the pilots changed their places and tasks, like in a real mission and flew back to their home destination.

Procedure

The researcher briefed the instructors about the study, the goal and their tasks. Instructors and researcher made a test trial to train the observation task.

The observational study began with the first briefing before the flight session. Besides the normal schedule of these briefings the instructor informed the pilots that they could participate, within the framework of a bachelor thesis, in an observational study. The cockpit crews, who chose to participate, signed the informed consent. After the first briefing, the instructor and the pilots went to the flight simulator. At the simulator, the pilots prepared the aircraft while the instructor filled in the information blocks on the observation form and the error protocol, with information over his name, the rank of the two pilots, the duration of the training, the time and the simulator type.

During the whole flight session the instructor used the error protocol and marked all pilot errors. The observation form, which measures the communication skills of pilots, was used by the instructor in five different situations, in the briefing before the take off, the take off, a take off with engine failure, the briefing before the final approach and the final approach. The instructor made on the observation form no differences between the situations. Reason for measuring during different flight situations was to get an average value of the communication skills from the pilots. The instructor observed the cockpit crew one minute in each of these situations and marked, on the observation form, how often the positive and negative behaviors occurred. When the cockpit crew arrived at the destination, pilots and instructors made a short break like in a real mission. The two pilots changed their places in the cockpit, before they were flying back to their home destination. The instructor used a second observation form and a second error protocol for this second flight.

Analysis

Scoring

The observation form was analyzed by summing up all marks in the frequency columns. Afterwards, the sum of using a good communication element was divided by the sum of using a good communication element and using its opposite. This leads to a communication coefficient with a value between 0 (never using a good communication element) to 1 (only using good communication elements). After the communication coefficients for all ten communication elements were calculated, all single communication coefficients were summed up and divided through ten. As a result, a total communication coefficient with a value from 0 (never using good communication elements) to 1 (only using good communication elements) was created.

Skill-based, decision-based and perceptual errors were summed up for each category. After this the total number of the three error types were summed up. This led to an overview of the total number of errors, the number of skill-based, decision-based and perceptual errors.

Data analysis

In order to analyze the connection between the use of the ten communication elements and the error rate of the pilots, a stepwise multiple linear regression analysis was done. This analysis was done for the ten communication elements and the total number of pilot errors. Furthermore, this analysis was carried out for the three error types skill-based, decision-based and perceptual with the ten communication elements. The stepwise multiple regression analysis is normally used to study the relationship between several independent variables and a dependent variable. This statistical method is analyzing the ability of each independent variable in predicting the dependent variable. Furthermore, this statistical method creates a model of different independent variables, which are best in predicting the dependent variable. This does not mean that the other variables are not able to predict the dependent variable. Some variables can be excluded from the final model even if they are able to predict the dependent variable. The reason is that these variables either have no supplementary value for the constructed model in predicting the dependent variable or their value, to predict the dependent variable, is already being predicted through another variable.

As a result this multiple regression produces a value R. The square of the value R describes how much of the variance in the dependent variable is being described or predicted through the model. The square of R can reach a value from 0 to 1. For example, a value of 0 means that 0% of the variance from the dependent variable is being explained through R square, a value from 0.5 means that 50% is being explained through the model and a value from 1 means that 100% of the variance is being explained through the model. Furthermore the value B describes, if there is a positive ($B>0$) or negative ($B<0$) relation between the variables. An alpha level of 0.01 was used, to test whether the models are significantly related to the number of errors.

Results

Number of Errors

The total number of errors and the total number of skill-based, decision-based and perceptual errors are shown in Table 3. The table includes also the maximal (Max.) and minimal (Min.) number of errors during one flight session as well as the mean value.

Table 3

Number of errors during the observation study

	Total	Max.	Min.	Mean value
Total Number of Errors	187	19	1	8.3
Skill-based errors	93	10	0	4.0
Decision-based errors	73	8	0	3.4
Perceptual errors	21	4	0	0.9

Stepwise Multiple Regression analysis

The ten communication elements, introduced in the introduction of this paper, were used in four different step wise multiple regression analysis to predict the total number of pilot errors, skill-based errors, decision-based errors and perceptual errors. The correlations of the ten communication elements, the communication coefficient, the total number of errors and all three the types of errors are represented in Table 4.

Total number of errors

The first stepwise multiple regression analysis was conducted to test if all ten communication elements are necessary in order to predict the total number of pilot errors. The communication elements *Pilots keep constant speech volume* (B = -.129) and *Pilots use short words* (B = -.093) were entered in step 4 into the regression equation and were significantly related to the total number of pilot errors F (2, 20) = 29,7, p < 0.001. The multiple correlation coefficient R was 0.87, with R square 0,757. The other communication elements were not entered into the regression equation in step 4 (all ts< 1.2, all ps> .05).

Skill-based errors and communication elements

The next step of the data analysis was to conduct a stepwise multiple regression analysis in order to test if the ten communication elements are necessary to predict the total number of skill-based errors during a check flight. The communication elements *Pilots keep constant speech volume* (B = -.09), *Pilots use short words* (B = -.066) *and Pilots use correct Readbacks* (B = .037) formed after step 3 the regression equation and were significantly related to the total number of skill-based errors F (3, 19) = 29,3, p < 0.001. The multiple correlation coefficient R was 0.91, with R square 0.83. The other communication elements were not entered into the regression equation in step 3 (all ts< 1.2, all ps> .05).

Table 4
Spearman-Rho correlation for the measured values

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Total communication coefficient	_														
2. Total Number of Errors	-.81**	_													
3. Skill-based errors	-.66**	.93**	_												
4. Decision-based errors	-.83**	.88**	.68**	_											
5. Perceptual errors	-.70**	.78**	.72**	.61**	_										
6. Using simple vocabulary	-.74**	-.70**	-.58**	-.70**	-.58**	_									
7. Using short words	-.72**	-.77**	-.77**	-.64**	-.58**	.64**	_								
8. Using the first person plural (we)	-.60**	-.35	-.20	-.43*	-.44**	.33	.03	_							
9. Keeping a constant speech rate	-.70**	-.78**	-.71**	-.75**	-.57**	.74**	.72**	.20	_						
10. Keeping a constant speech volume	-.71**	-.76**	-.71**	-.67**	-.75**	.42*	.50*	.46*	.67**	_					
11. Enunciating words clearly	-.67**	-.65**	-.71**	-.51*	-.61**	.50*	.64**	.39	.56**	.58**	_				
12. Using standard call-outs.	-.61**	-.49*	-.33	-.47*	-.38*	.54**	.60**	.20	.41	.26	.13	_			
13. Using FMA call-outs.	-.42*	-.42*	-.16	-.64**	-.26	.30	.06	.28	.37	.35	.04	.21	_		
14. Making a correct Readback	-.71**	-.57**	-.52**	-.57**	-.66**	.34	.46*	.44*	.48*	.82**	.63	.22	.17	_	
15. Using all information sources.	-.28	-.20	-.10	-.30	-.22	-.13	.11	.35	.01	.44*	.11	.12	.04	.53**	_

**Correlation is significant at the 0.01 level.
*Correlation is significant at the 0.05 level.

Decision-based errors and communication elements

The model to predict decision-based errors was reached in four steps including the communication elements *Pilots keep constant speech rate* (B = -.057), *Pilots use FMA call-outs* (B = -.021) and *Pilots use all available information sources* (B = -.027). This model was significantly related to decision-based errors $F(3, 19) = 18{,}5$, $p < 0.001$. The multiple correlation coefficient R was 0.863, with R square 0.75. The other communication elements were not entered into the regression equation at step 3 (all ts< -0.5, all ps> .05).

Perceptual errors and communication elements

The last model, which was calculated for this study, was reached in two steps and includes the communication elements Pilots use the first person plural (we) (B = -.019) and Pilots keep a constant speech volume (B = -.016). The model was significantly related to the number of perceptual errors $F(2, 20) = 12{,}7$, $p < 0.001$. The multiple correlation coefficient R was 0.748, with R square 0.56. The other communication elements were not entered into the regression equation in step 3 (all ts< 1.1, all ps> .05).

Conclusion and Discussion

The aim of this study was to investigate whether the pilots´ use of language can influence the flight performance of cockpit crews. A pretest was executed in order to identify communication elements, which are able to indicate good intra and/or inter cockpit communication. These communication elements have been used to create an observation form. Afterwards, this form was used during a couple of check flights in a Flight Training Center and the results were compared to an error protocol. This error protocol has been developed on the basis of the Human Factors Analysis and Classification System (U.S. Department of Transportation, 2000). As a result, the study can not conclude that the pilots´ use of language is influencing the flight performance of cockpit crews, however associations between errors and communication skills were found.

Total number of errors

At first, the associations and correlations between the communication elements and the total number of errors were analyzed. The total communication coefficient was significantly and negatively correlated to the total number of pilot errors. In contrast to the study of Sexton and Helmreich (2000), the correlation between the total number of pilot errors and the use of the communication element (using the first person plural) was not significant. Furthermore, the communication element (using first person plural) was no part of the model that is best in describing the association between communication skills and the total number of pilot errors. This model contained the communication elements (keep constant speech volume and use short words) and was associated with 74,8% of the variance of the total number of errors. Furthermore, a decreasing number of errors was associated with a frequent use of the communication elements (keep constant speech volume and use short words).

Skill-based errors and communication elements

The study further showed that six of the ten communication elements were significantly and negatively correlated to the number of skill-based errors. Not all communication elements were necessary to describe the strongest association between skill-based errors and the communication skills of the pilots. A model including the communication elements (keep constant speech volume, use short words and use correct "Readbacks") was strongest associated with the total number of skill-based errors. A frequent use of the communication elements (keep constant speech volume and use short words) and an infrequent use of the communication element (use correct Readbacks) were associated with a decreasing number of skill-based errors and were associated with 82,2% of the variance.

Decision-based errors and communication elements

Decision-based errors were significantly correlated with nine of the ten communication elements. Only the communication element (use all available information sources) was not significantly correlated with decision-based errors. Regardless of this fact, this communication element (use all available information sources) was part of the final model that is strongest associated to with this type of error. The reason was that the communication element (uses all available sources to get information) was not correlated with most of the other communication elements. Therefore, this communication element, in a model with the other communication elements, has a supplemental value to describe the association between communication skills and decision-based errors. The model contained the communication elements (use FMA call-outs, use all available information sources and keep a constant speech rate) and was associated with 75,4% of the variance of decision-based errors. Furthermore, a decrease of decision-based errors was associated with a frequent use of the three communication elements (use FMA call-outs, use all available information sources and keep a constant speech rate).

Perceptual errors and communication elements

The number of perceptual errors was significantly correlated with eight of the ten communication elements. A model that contained the communication elements (Pilots use the first person plural and Pilots keep a constant speech volume) was strongest associated with the number of perceptual errors and was associated with 56% of the variance of this type of error. The frequent use of these communication elements was associated with a decrease of perceptual errors.

The link to psychological theories

The results of this study show that the association between the pilot´s use of language and their flight performance should be investigated in further research. In contrast to the study of Sexton and Helmreich (2000) no significant correlation between the total number of pilot errors and the use of the communication element (use the first person plural) was measured. The experiment of Sexton and Helmreich (2000) has been executed with the old cockpit crew setup, including two pilots and one flight engineer. As discussed by the authors, this was a main limitation of their study because the old, more hierarchical, setup cannot be compared to the new, less hierarchical, setup. These hierarchical differences might be responsible for the different results. This finding should be considered during further research. The communication element (using the first person plural) could be more important for teams with a strong hierarchical system than for teams with a weak hierarchical system. Maybe this communication element would be significantly related to the number of errors, if the study would include the communication with the cabin crew. As described by Chute (1995) and Chute (1996) the hierarchical structures between cockpit crew and cabin crew are the biggest reason for communication problems between these two crews. Based on the represented data this study is not able to make a causal statement. Taking into account the results from Sexton and Helmreich (2000), it should be considered that the hierarchical system of the professional teams might influence the importance of the different communication elements. This is important because communication in safety critical environments takes not only place in aircraft cockpits but also between e.g. medical teams. The hierarchical structures of these teams are very different, which is why it should be considered that this structure maybe determines how important certain communication elements are.

As expected significant and negative correlations between the communication elements (using simple vocabulary, using short words, keeping a consistent speech rate, enunciating each word clearly and distinctly, having constant speak volume, using correct

Readbacks) and the number of skill-based errors were measured. These correlations were expected because the use of these communication elements should make messages comprehensible, according to the pretest of this study, or the ICAO (2010) or Sexton and Helmreich (2000). As a result, pilots need less time to interpret a comprehensive message compared to an incomprehensible message. In return, this would decrease the workload of the aircraft pilots, as workload is defined as: time required (to perform tasks) / time available (Wickens, 2002). Pilots with a high workload would get problems to focus their attention on their basic flight tasks (Wickens, Lee & Becker, 2004) for which reason skill based errors occur (U.S. Department of Aviation, 2000). If further research underlines the importance and investigates the relation between these communication elements and workload, communication trainings (not only for cockpit crews but also for other professional teams) could be developed. As professional teams are able to communicate more automatically in high workload situations, this could maybe decrease their workload caused through the communication tasks and decrease the influence from the communication tasks on the other tasks, see Figure 5 (Navon & Gopher, 1979).

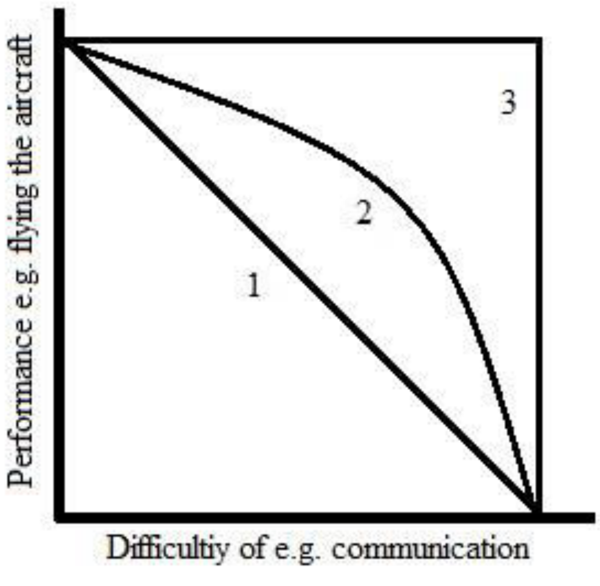

Figure 5 Theoretical depiction of how (1) low, (2) medium, and (3) good communication skills are associated with pilot performance.

As discussed in the introduction, shared mental models, are very important for an effective decision-making process (Orasanu, 1990; Orasanu, 2000; Reynolds, Blickensderfer, 2009). To update or to create these mental models, pilots need information over the current state of their aircraft (Baxter, Besnard, & Dominic, 2007). To inform each other over changes of the current state of the aircraft, cockpit crews use call-outs (Airbus, 2004). As expected, significant and negative correlations between the communication elements (use of standard call outs and use of FMA call-outs) and the number of decision-based errors were measured. It was further expected that pilots have to use all available sources to get information, firstly to prevent a mismatch between the real world and their mental model (Baxter, Besnard, & Dominic, 2007) and secondly to obviate the activation of a wrong mental schema (Plant & Stanton, 2012). The communication element (use all available sources to get information) was not significantly correlated to the number of decision-based errors but it entered the model that is best at describing the association between communication skills and decision-based errors.

The model, which best describes the association between the communication skills of aircraft pilots and the number of perceptual errors, is less able to describe the variance of perceptual errors (56%) compared to the models for skill-based errors (82,2%) and decision-based errors (75,4%). This was expected because perceptual and communication tasks are most of the time executed in different brain areas (Wickens, 2002). Thus, the two tasks are influencing each other most of the time only through non-shareable resources like the working memory (Wickens, 2008).

Further Research

Further research should investigate for which reason the associations between communication skills and pilot errors exist. Therefore, further research should measure at which moments errors or good/bad communication occurs. This would make it possible to investigate whether bad communication occurs before pilot errors occur or if a third variable is responsible for the measured association. A possible method to investigate for which reason the correlations and associations between decision-based errors and the communication elements exist, is to use think aloud-verbal protocols. Cockpit crews could be filmed during their flight training and situations in which decision-based errors mostly occur could be simulated. After the flight, training pilots could watch the video and say loudly what they were thinking during the situation in the video. This would make it possible to investigate if a false schema, overtrust, or mental models are responsible for decision-based errors.

If the results would show that the pilot´s use of language is influencing their flight performance, airlines have to develop special communication trainings that include the identified communication elements. This could have a positive affect for the safety in aviation and could obviate serious aircraft accident during like the Kegworth disaster presented in the introduction of this paper. These communication elements could be added to NOTECH system or a category “communication“ could be implemented, which would allow the flight instructors to give the pilots a better feedback after their LOFT training with respect to their communication skills.

Limitations

This study has some limitations, which should be considered in the conclusions. The observation study takes place in fully-flight simulators. These simulators are the best option to simulate a flight in a real aircraft, but they are still simulations, which are supervised by a flight instructor. The pilots know that and they know further that they could fail the check flight, which would have consequences for their career advancement. This could have influenced their behavior during the check flight and it is not sure, if the pilots would behave in the same way during a real flight. Furthermore the sample size is limited. A bigger sample size would give the results more power and would decrease the influence of extreme scores. Another limitation is the stepwise multiple regression analysis. It is possible that this statistical method excluded communication elements, which are only slightly worse than another communication element. These differences could occur because of random variation in the data. This random variation could cause that communication elements, which are actually better in predicting some kind of errors, get excluded. It is also possible that the observers had some influence on the data. The researcher briefed the observers and a test observation was made. A real observer training, in which all observers have to observe a couple of cockpit crews together, would increase the validity and the reliability of this observation study. After this test observations the inter-rater reliability could be calculated and observers with extreme scores could be excluded or receive further training.

Final Statement

It is obvious that further research is necessary in order to investigate in how far the pilots’ use of language is associated to the flight performance of the cockpit crews. The current study has measured correlations between certain communication elements and certain types of pilot errors and mentioned psychological theories, to find possible explanations for this associations. Based on the represented data, the current study cannot make causal statements or name reasons why these associations exist. The existence of a third variable or that bad flying skills have influenced the communication skills cannot be excluded. Based on the represented data it can be concluded that an association between communication skills of aircraft pilots and their flight performance exist, but further research is necessary to investigate why this associations exist.

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Appendix A

Name Instructor							
Date		Training Duration					
Time		Simulator Type					
Rank 1. pilot		Captain		or	FO		
Rank 2. pilot		Captain			FO		

Use the tool...

1 = During Take-off briefing

2 = During Take-off

3 = During Take-off with engine failure

4 = During Approach briefing

5 = During Final Approach

Behavior (a)	Frequency a	Behavior (b)	Frequency b
Structure of the sentences			
Pilots use simple vocabulary if they speak more than 5 seconds.		Pilots use difficult vocabulary if they speak more than 5 seconds.	
Pilots use short words if they speak more than 5 seconds.		Pilots use long words and sentences if they speak more than 5 seconds.	
Pilots use the first person plural (we) while speaking with each other.		Pilots use the first person singular (I) or the second person singular/plural (you).	
Use of language			
Pilots keep a constant speech rate if they speak more than 5 seconds.		Pilots change their speech rate if they speak more than 5 seconds.	
Pilots keep a constant speak volume if they speak more than 5 seconds.		Pilots change their speak volume rapidly if they speak more than 5 seconds.	
Pilots enunciate words clearly if they speak more than 5 seconds.		Pilots enunciate words unclear if they speak more than 5 seconds.	
Use of standards			
Pilots use standard call-outs.		Pilots do not use standard call-outs.	
Pilots use FMA call-outs.		Pilots don´t use FMA call-outs.	
Pilots make an correct readback.		Pilots make an incorrect readback.	
Gathering information			
Pilots use all sources of information.		Pilots use not all information sources.	

Appendix B

Error protocol

Name Instructor			
Date		Training Duration	
Time		Simulator Type	
Comments:			

Errors

Skill-based Errors like:		**Number of Errors**
•Breakdown in visual scan		
•Failed to prioritize attention		
•Inadvertent use of flight controls		
•Omitted step in procedure		
•Omitted checklist item		
•Poor technique		
•Over-controlled the aircraft		
Decision Errors like:		
•Improper procedure		
•Misdiagnosed emergency		
•Wrong response to emergency		
•Exceeded ability		
•Inappropriate maneuver		
•Poor decision		
Perceptual Errors like:		
•Misjudged distance/altitude/airspeed		
•Spatial disorientation		
•Visual illusion		
	Total Number of Errors	