Language and action in the cockpit: a view from the Theory of Distributed Cognition

Linguagem e ação no *cockpit*: uma visão da Teoria da Cognição Distribuida

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ABSTRACT: *Many of the maneuvers performed by pilots during a flight are the result of instructions received from air traffic control. The execution of these maneuvers requires the engagement of different cognitive processes, of which language is a component of vital importance. This article presents a theoretical-conceptual model, the Theory of Distributed Cognition, as an adequate basis for the investigation of linguistic experiences occurred in the interaction with technological artifacts that exist in the pilot's work environment. From a view of cognition as a distributed phenomenon, I explain how an air traffic control instruction can take different forms of representation, propagate through the environment and manifest itself in the actions resulting from its compliance.*
KEY WORDS: *distributed cognition; language and technology; language in aviation.*

RESUMO: *Grande parte das manobras realizadas pelos pilotos durante o voo é resultante de instruções recebidas do controle de tráfego aéreo. A execução dessas manobras requer a mobilização de diferentes processos cognitivos, dos quais a linguagem é um componente de vital importância. Este artigo apresenta um modelo teórico-conceitual, a Teoria da Cognição Distribuída, como arcabouço teórico adequado para a investigação das experiências linguísticas ocorridas na interação com os artefatos tecnológicos existentes no ambiente de atuação do piloto. A partir de uma visão de cognição como fenômeno distribuído, apresento como uma instrução do controle de tráfego aéreo pode assumir diferentes formas de representação, propagar-se pelo ambiente e manifestar-se nas ações decorrentes do seu cumprimento.*
PALAVRAS-CHAVE: *cognição distribuída; linguagem e tecnologia; linguagem na aviação.*

1 Introduction

The world we live in undergoes constant changes as a result of human activity and, to a considerable extent, the bulk of that activity can only be achieved through coordination made possible by the use of language. As in any realm of human activity, communication plays a leading role in aviation operations, with undeniable importance for safety in all phases of flight. Many of the actions performed by pilots while carrying out the necessary procedures to take an aircraft safely from one airport to another are the direct result of language input, in the form of instructions received from air traffic control – ATC. The execution of these actions involves different types of cognitive processes and is the consequence of the interpolation of

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environmental information with internal representations mediated by language (Chuah; Zhang; Johnson, 1998). Part of these processes is dependent on the higher mental functions (Vygotsky, 1978) and are primarily seen as internal to the individual. Higher mental functions include, but are not limited to, logical reasoning, memory, attention, problem solving, and decision making. Other processes, however, involve the coordination between higher mental functions with external media, such as instruments and other related artifacts used during the execution of flight tasks (Hollan et al., 2000).

It is widely recognized (Hutchins; Klausen, 1995; Holder, 1999; Hollan et al., 2000) that the pilot's work setting abounds with artifacts that not only amplify his or her organizational capacity but whose operation involves a constant traffic of representations, both triggered by and mediated by language, that propagate through the environment, resulting in the desired flight profile. In this article, I will introduce a theoretical frame that takes into account cognitive systems that extrapolate the physical boundaries of the individual and permits the study of linguistic events mediated by technological artifacts, allowing for a more comprehensive understanding of the ramifications of language use in the cockpit. First, I will present an overview of the Theory of Distributed Cognition and comment on how the use of its principles can shed light on the relation between language and action in the cockpit. Then, I will illustrate how a specific ATC instruction received in the cockpit relates to the environment and propagates through technological media. Finally, I will conclude the article by suggesting a research agenda that can possibly bring important contributions for the study of the situated use of language in aviation.

2 Cognition as a distributed phenomenon

Cognitive science is a relatively new field of enquiry that looks into matters related to the dynamics of cognitive processes and congregates disciplines of psychology, neuroscience, linguistics, anthropology, and computer science, among others (Matlin, 2003). Traditionally, mainstream cognitive science considers cognition as the mental processes that occur within an individual's brain, not taking into consideration the role that the physical and the social environment play in human activity (Flor; Hutchins, 1991; Hollan et al., 2000; Hutchins, 1995; Rogers, 1997, 2006). More recently, a notion of cognition that has been attracting considerable attention is one that sees cognitive processes as intimately related to the interactions between mind, body and environment (Gibson, 1986; Wilson, 2002). According to this view, cognition is both embodied and situated, by which its proponents mean that our sense of the world is essentially dependent on the sensory-motor mechanisms developed in our interaction with the environment, and largely contingent on the contextual frame in which it is manifested.

One branch of cognitive studies that makes use of the notion of cognition as a phenomenon that surpasses the physical boundaries of the individual is the Theory of Distributed Cognition (henceforth, DCog). The emergence of DCog is more frequently associated to studies conducted by the American anthropologist Edwin Hutchins. Hutchins brought DCog to light when he published a number of articles describing the cognitive processes involved in the navigation of a US Navy ship (Hutchins, 1995, 2000).

DCog, like other lines of cognitive science, seeks to understand the inner workings of cognitive systems. Unlike other lines, though, DCog extends the concept of cognitive system beyond the individual, to include the interactions between people and technological artifacts in the environment (Hollan et al., 2000). Hutchins (2000) explains that two core principles distinguish DCog from other approaches: a) the limits of the units of analysis that can be considered in studies of cognition; and b) the variety and range of mechanisms that may play a role in cognitive processes.

With regard to the first principle, Hollan et al. (2000) point out that DCog looks for cognitive processes wherever they might occur, based on the functional relations between the elements involved in the process. The authors argue that a process is not cognitive just because it happens in the brain, nor does it cease to be cognitive simply due to the fact that it takes place in the interactions between brains or between a brain and artifacts in the environment. Hutchins (2000) emphasizes that, for DCog, a cognitive system, as unit of analysis, comprises people and the artifacts that they use. As an example, the author defined as the unit of analysis in one of his studies the many interactions between people and between people and artifacts, in the process of navigating a ship, during the critical phase of its arrival at the port. Hutchins (1995) explained that the task of navigating the ship is accomplished by a team whose members are positioned in different parts of the ship, who coordinate with one another through language, with the engagement of a number of artifacts especially developed for this task. In this scenario, the individuals and the artifacts are elements of a system that is characterized by the functional relations between its components, regardless of their physical location.

The second principle refers to a whole host of mechanisms that can be taken into consideration as contributing to cognitive processes. Hollan et al. (2000) exemplify that, in an analysis of cognitive processes taking place in the cockpit of an airplane, the study of the pilot's internal memory might not yield sufficient data for a comprehensive understanding of the activity. The authors suggest that a more accurate analysis of this particular environment would reveal "[...] a rich interaction between internal processes, the manipulation of objects, and the traffic in representations among the pilots" (Hollan et al., 2000, p. 3). It is also possible to consider here the flow of representations afforded by the cockpit instruments, and the traffic of representations between the pilots and the air traffic controller, which takes place, predominantly, through the use of language. Hutchins (1995) emphasizes that such an analysis reveals not only a pattern of cooperation and coordination, but also unveils an activity system in which cognition, shared and distributed through mediating artifacts, emerges as one of its characteristics. Pea (1993) reminds us that, although it is people who carry out an activity, artifacts commonly guide and amplify the activity, and the solution of problems involves cognitive processes that include the mind and available mediating structures.

The interplay of these two core principles of DCog generates cognitive systems whose dynamics enable different configurations, so that the coordination of their sub-systems allows for the execution of multiple functions. Hollan et al. (2000) point out that, when these two principles are taken into account in the analysis of human activity in its ecological context, it is possible to identify three forms of distribution of cognitive processes:

a) cognitive processes can be distributed among the members of a social group;
b) cognitive processes can be distributed in time, so that the product of earlier events can transform the nature of later events; and
c) cognitive processes can involve the coordination between mental structures and material or environmental structures.

In any endeavor, coordination of the activity between individuals creates a synergy that permits the attainment of objectives that would be impractical to an individual alone. This coordination is independent of the proximity of is participants. Current technology offers collaborative tools that enable the coordination between people regardless of where they are in the world. In aviation, examples of the social distribution of cognitive processes abound, an example being the collaborative work between a pilot and an air traffic controller.

The distribution of cognition in time refers to the influence that human activity exerts over future experiences of similar activities. In aviation, instances of this sort of distribution are also common. One classic example is how the careful analysis of an incident or accident reveals contributing factors that are then made public to prevent future occurrences that might lead to the same outcome.

The third form of distribution of cognition refers to the influence that the physical environment has on cognitive activity and constitutes a particularly rich ground for studies that focus on the relation between language and action. One important characteristic of human-artifact coordination is that using artifacts not only changes the nature of the activity, but also brings improvements to it when compared to the same activity performed without the aid of mediating artifacts. In flying an airplane, for instance, making a turn with the use of the autopilot is different from making a turn by hand. Also, it is a common perception among aviators that, in comparison to a human pilot, the autopilot does a much better job of maintaining a constant rate of turn, while maintaining altitude and speed, even in turbulent air conditions. In this sense, we can confirm that the use of artifacts serves the purpose of enhancing our physical abilities. Besides this, Hutchins (2000) affirms that the use of technological artifacts also enhance our cognitive capacity. To this end, the pilot's environment is filled with technological artifacts, in and outside the cockpit, which provide an abundant flow of information that feeds the decision making process in a way that would be impossible to achieve without their existence. It is important to remember that both physical tools and symbolic systems, including language, mediate human activity (Vygotsky, 1978).

Hutchins (1995) and Rogers (1997, 2006) refer to cognitive processes as computational operations that occur through the propagation of representational state through media. The notion of representation and its processes of propagation constitute a central tenet of DCog. Holder (1999) defines representation as a structure that can be interpreted as meaning something other than itself. Strasser (2010) affirms that representations present something as something else for somebody. Representations can be internal or external. They can occur in the mind of an individual or in the environment (Holder, 1999; Strasser, 2010; Zhang; Norman, 1994). Internal representations are thoughts, mental images, schemas and models. External representations manifest in the physical world, in which an object is taken to represent another object, a situation, a concept or a process. Holder (1999) points out that, in a distributed system, a representation is only such in the interaction with the other components of the system. This interaction suggests that representations are dynamic elements, that assume states that are specific to a given moment. These states undergo transformations as the representation evolves in the course of an activity. Language, as a representational system (Vygotsky, 1978) plays a part in these transformations.

It is my understanding that the analysis of the specificities of language use in the cockpit could benefit from a solid understanding of the interdependence between language and the use of technological artifacts, and how this interplay translates into representations that propagate through the pilot's environment. In the next section, I will examine this relation in more detail.

3 The propagation of language in the cockpit

The actions that take place in the cockpit, in response to instructions issued by an ATC facility, require the integration of different flows of dynamic representations, from different sources and in different representational states, for the pilot to form a clear understanding of the current condition of the aircraft, the intended condition, and the actions that are necessary to attain the desired change. These representations include language, charts, displays, checklists, notes, and also signs, markings, lights, and other physical features of the environment outside the cockpit that must be interpreted in the course of the activity. Besides interacting with one another and with the air traffic controller, the pilots also interact with the flight controls, with the instruments on the panel, and with the external mediating artifacts that undergo frequent changes along the flight. The identification of these interactions and the description of how language, as a representational system, propagates through the mediating artifacts can clarify the meaning that is attributed to a specific utterance, from the moment it is received by the flight crew. DCog seems to offer an adequate theoretical frame for such an endeavor.

In a study conducted recently with Brazilian pilots, I examined how specific ATC instructions assume different states as a result of triggered actions that propagate, moment by moment, through the environment, in a constant traffic of representations involving different types of technological artifacts. As an example, an apparently simple instruction, such as *taxi to runway one three left via taxiways golf, bravo, uniform* triggers a series of actions that cause language to assume different forms of representation that constantly change, as the aircraft moves from one point to another on the surface of the airport. Also, even a cursory inspection of the process reveals the manifestation of the three forms of distribution of cognition advocated by Hollan et al. (2000). To begin with, social distribution of cognitive processes is exemplified in the coordinated actions between the pilots in the cockpit, as well as in the interaction between the pilot and the controller, which is essential for the organization of ground traffic. From the control tower, the ground controller has a bird's eye view of the entire area of the airport. The pilot's view is rather restricted to the immediate surroundings of the aircraft. Complementary background knowledge, a shared linguistic code, and a common understanding of the technical aspects of the intended operation allow for the achievement of results that the pilot alone would have difficulty to achieve.

A taxi instruction is a verbal representation of a sequence of maneuvers that the controller needs the pilot to perform in order to ensure the safe, orderly and expeditious movement of all the aircraft operating on the surface of the airport at any given time. At airports with a complex layout or with which the pilot is unfamiliar, a common practice is to write down the taxi clearance to facilitate read-back and later comparison with the airport chart. The writing down of the clearance constitutes the first observable transformation in the form of representation, in this case from oral language to written language. During the read-back process, the reverse occurs, when the pilot transforms his notes back into an oral representation of the intended operation that is transmitted to the controller for verification. Further transformation occurs when the pilot compares his notes with the airport chart to determine the assigned route to be followed on the ground from the aircraft's present position to the assigned runway. Another common practice used by pilots is to draw a line on the chart to facilitate the ensuing procedures. The line on the chart is, again, another representation of the oral instruction received earlier.

The chart used in the cockpit is a representation of the world outside the cockpit (Hutchins, 1995). The movement of the aircraft on the ground requires the transposition of the representation of the route to be followed, from the chart to the complex array of taxiways that possibly exist at a major airport. In other words, the accomplishment of the intended sequence of maneuvers depends on the constant interaction with an artifact in the cockpit and with a number of representational artifacts outside the cockpit. Navigation on the ground is made by comparing symbols on the chart with physical features of the environment, with the aid of artifacts placed at specific locations on the surface of the airport, such as signs, markings painted on the ground, and lights (FIG 1).

FIGURE 1 – Artifacts on the surface of the airport help determine the aircraft's position

During the process of taxiing the aircraft from the ramp to the assigned runway, the success of each step determines the conditions for the performance of the next maneuver. One missed turn can lead to a totally different and possibly undesired outcome. This situation seems to illustrate appropriately how cognitive processes are distributed through time.

It is important to remember that fragments of the initial taxi instruction will resurface periodically along the taxi process, as the aircraft approaches key intersections where the pilot needs to decide which way to turn and what taxiway to take next. All this happens at the same time as the pilot has to carry out other tasks, like verifying items of the *checklist* or addressing the passengers, for instance.

It seems reasonable to assume that, without the use of the aforementioned artifacts, it would be very difficult for a pilot to taxi an aircraft along a specific route on the surface of a major airport, with numerous taxiways and multiple runways. This situation reveals the continuous and complex interdependence of social, temporal and material factors that are at play in the process of taxiing an aircraft. Also, it points at the constant interplay between mental processes and external representations, be they paper artifacts, electronic instruments or other objects placed in the environment. Language permeates all these processes and not only triggers actions but lingers throughout an operation taking different forms of representation as the aircraft moves along the way. As part of an ATC instruction, the meaning of a word extrapolates its dictionary definition and acquires the weight of the actions that it generates.

4 Conclusion

In this article, I tried to demonstrate how a theoretical model of cognition that takes as its units of analysis cognitive systems that extrapolate the physical boundaries of the individual can contemplate the linguistic involvements associated with the receipt of ATC instructions in the cockpit. The ecology in which language occurs in this domain calls for a theoretical frame that permits the exploration of linguistic phenomena that emerge as a result of human interaction with mediating artifacts that organize activity. DCog, originally developed to describe and interpret human interaction with technological artifacts, seems especially fit to meet this demand.

By overcoming the distinction between what is considered to be internal and what is taken to be external cognitive processes, DCog enables us to devote a broader look at the linguistic experiences that arise from the activity of flying an aircraft, in terms of their social, temporal or environmental ramifications. This theoretical frame entitles us to see the language of air communications not as an isolated entity, detached from its manifestation in the world, but, rather, as a critical component of a larger system that encompasses the controller, the pilot, and the mediating technological artifacts in the cockpit and beyond.

These considerations signal possible opportunities for further research. First, it seems reasonable to suggest studies that deepen the understanding of the situated use of language in routine operations, mapping its mechanisms of propagation in all phases of flight. Another issue worth addressing is the effect that the pilot's engagement with technological artifacts possibly exerts over language processing, particularly during emergency situations. Evidently, similar studies, conducted in the universe of air traffic controllers, could harvest potentially promising results as to the understanding of the relation between language and technology in that domain. Finally, I believe that a comprehensive awareness of the linguistic experiences brought about in the interaction with technology can translate into vital contributions for both the academic and the aviation communities, ultimately feeding the design of pedagogical interventions that seek to approximate language instruction to the involvements of the work setting.

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