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In the aviation human factors literature, situation awareness (SA) is usually described as arising from disembodied mental processes. Action has virtually no role in current theories of SA. This disembodied view is out of step with contemporary theories that take cognitive processes to be distributed, situated, and above all, embodied. This shift in theory suggests that SA ought to be an embodied phenomenon, and given the highly spatial nature of SA, it would be quite surprising to discover that the body did not play a key role in the construction, elaboration, and maintenance of SA. In this paper we examine the construction of elements of SA in ongoing flight training conducted in a light jet. We show that flight instructors and students make extensive use of their bodies and the relations of their bodies to surrounding space while constructing, remembering, and reasoning about the situation of the airplane.

When pilots transition to a new airplane, they must learn how to think about dynamic flight trajectories in ways that match the performance of the airplane. Awareness of spatial relationships between the airplane and its surroundings is a key element of situation awareness (SA). Contemporary aviation human factors seems to take SA to be a purely mental construct. Endsley (2000) provides a general definition of situation awareness: “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.” For Endsley and many others, this is a one-way process of information input. There is no consideration of the role that bodily activity plays in perception, comprehension, and imagination of the future. For example, Bowers, Jentsch, & Salas (2003) claim that situation awareness is in large part collecting instrument information to construct a “mental picture” of the situation. They also discuss coordination, decision-making, adaptability, and performance monitoring without explicitly mentioning the body. The DoD’s Aviation Safety Improvements Task Force (2009) acknowledges the body as a locus of disease, fatigue and reaction to environmental conditions. Of course the body is given a role in perception and action. However, with respect to communication, reasoning, and conceptualization (for example in constructing the spatial aspects of situation awareness), the body is given no role at all. Crew Resources Management training (O'Connor, Campbell, Newon, Melton, Salas, & Wilson, 2008; Seamster, Boehm-Davis, Holt, & Shultz, 1998) treats both decision-making and situational awareness as “mental factors” and includes no consideration of the role of the body or action in constructing them. Banbury, Dudfield, Hoermann, & Soll (2007) provide a rare exception, noting the importance of non-verbal communication in the construction of situation awareness. The design of pilot interfaces sometimes confronts the reality of the presence of a body. For example, situation awareness can be improved by adding cues in haptic and auditory channels (Lam, Mulder, & van Paassen, 2007; Wickens, Small, Andre, Bagnall, & Brenaman, 2008; Curry, Estrada, Grandizio, & Erickson, 2008).

We believe that the failure to attend to bodily action in the creation of SA is a serious omission because the body is an important resource in these processes and because activities that interfere with the employment of the body in these processes degrade performance. A growing body of research shows that real-world meaning making is multimodal, involving the coordination of verbal and non-verbal behavior with the elements of a shared culturally meaningful setting for action (Goodwin, 1994; Goodwin, 2000; Hollan, Hutchins, & Kirsh, 2000; Hutchins, 1995).

Video data collected in flight instruction in light business jets show how flight instructors and students use their bodies to conceptualize and communicate about the spatial situation of the airplane. Gestural resources in multimodal communication are likely to be especially important when instructor and student do not share native language or culture (Hutchins, Nomura, & Holder, 2006; Nomura & Hutchins, 2007).

Methods

The setting

Through an agreement with a flight school located in Southern California we made video and audio recordings of flight training. In this paper we analyze four training flights conducted in two different light corporate jets, the Cessna Citation I (Model CE-500), and the CitationJet (Model CE-525). The training curriculum included four days of ground school covering the aircraft systems and performance, flight maneuvers, cockpit resource management, and instrument approach flight profiles. The ground school was followed by three days of in-aircraft flight training, and finally, a pass/fail check ride administered by an FAA Designated Pilots Examiner (DPE).

Student # 1 was a 30 year old male ab-initio cadet for a major airline based in Korea. He came to the US earlier for his elementary flight training where he accumulated 256 hours of flight time flying small single-engine and multi-engine piston aircraft. That flight training was conducted at another flight school and was unrelated to this training event. He had a small amount of experience in the Boeing 737 simulator. He held a Commercial Pilot Certificate with Multi-Engine and Instrument Ratings. Student # 2 was a 28 year old French woman who had been working as a flight instructor in Normandy for about one year. She held a Commercial Pilot Certificate with Multi-Engine and Instrument Ratings, as well as a Flight Instructor Certificate. Her total aircraft time was approximately 1935 hours and she had no prior jet experience. Student # 3 was a 60 year old American male, recently retired from the position of captain flying the B737 for a US-based airline. As a career airline pilot, he accumulated approximately 20,000 hours of flight time, and held Airline Transport Pilot and Flight Instructor certificates with ratings in numerous big jets. Two flight instructors, one 38 year old male (Instructor M) and one 34 year old female (Instructor F) conducted the observed training. Instructor F holds an Airline Transport Pilot Certificate and holds two jet type ratings, CE-500 and CE-525(S). Instructor M holds an Airline Transport Pilot Certificate and the following type ratings: AV-L39, CE-500, CE-525(S), CE-510(S), HS-125, LRJET, and WW24. Both instructors hold Multi-Engine Flight Instructor Certificates.

During all four training flights, the students occupied the left (Captain's) pilot seat and the instructor occupied the right (First Officer's) pilot seat. The researcher/observer operating video and audio equipment was also on board for all the flights. On some flights other students and the second flight instructor were also on board. The flights were planned as a standard first flight in a jet. The lesson plan included extended pre-takeoff checks, normal takeoff and climb followed by air work including steep turns, stall recoveries, unusual attitude recovery, then vectors to an instrument approach utilizing an Instrument Landing Systems (ILS). For some flights additional approaches were briefed and flown. The students hand-flew the entire flight with the exception of momentarily handing off controls of the aircraft to the instructor during transitions from one maneuver to the next.

All training flights were approximately 2 hours in duration. The role of the flight instructor was to train the student to perform the flight maneuvers and approaches to ATP standards. In addition to teaching and correcting errors, the instructor also acted as a co-pilot and performed duties such as communicating and coordinating with ATC, running checklists, briefing approaches, tuning navaids, and checking weather. The training fights were conducted under IFR in VFR conditions, with few exceptions when low-level costal stratus mandated actual IFR flight. The student and instructor communicated to each other using the airplane intercom system and both pilots wore standard corporate headsets. The instructor communicated with ATC over the push-to-talk system. The cross-cultural and cross-linguistic aspects of working with foreign students are not typical of the majority of flight training conducted in the US, but we expect it to become much more common as ab-initio programs expand abroad. Overall language differences between students 1 and 2 with their instructors were evident while student #3 was a native English speaker and had no difficulties communicating with both instructors.

Because of the dynamic environment of in-aircraft jet training some variables cannot be controlled, such as weather, ATC workload, the congestion at the airport, more or less chatter on the frequency, other airplanes practicing maneuvers and approaches that lead to more traffic calls, and mechanical problems with the airplane. Although the weather was generally mild throughout all training flights, sometimes IFR clearances or deviations from the original flight plan were necessary. For example, during the flight with student #1 and instructor F, the student had just completed the stall series when the instructor noticed that while it was possible to select the landing gear down and locked, it appeared not to lock in the "up" position. This unanticipated hydraulic problem put an end to the practice air work. It was decided to return to the airport with the gear down and locked. Thus, the approach vectors and ILS approach phases were normal except that the timing of gear extension was disrupted by the fact that the gear was already down.

Data Collection Procedures

The video data were collected with an apparatus we call the "HatCam" which consists of a small 150° field-of-view camera mounted in the brim of a ball-cap and feeding its video signal to a digital video cassette recorder. The HatCam was worn by the instructor and provides a good image of the cockpit environment as shown in figure 1. To record the audio, lapel microphones were clipped to the shirts of both the instructor and the student. Cockpit noise is low enough that the participants can speak in normal voice levels. Air Traffic Control radio frequency was routed to an overhead speaker. The audio signal was recorded onto a digital audio recorder. After the flight the video data was digitized and the audio data was synchronized and added as a track on the video.

Data Analysis Procedures

The analysis began with careful review of the videos. We selectively transcribed the videos, noting all instances of constructions of representations of spatial relations by either instructor or student. To define the boundaries of events, we focused on the representation of relationships of the airplane to spatial or conceptual entities that are elements of situation awareness. We produced a selective transcript table that included all such events. To generate quantitative measures, we defined a set of attributes of the events and then coded every event for the chosen attributes. We coded the primary author of the representation, the referent(s) of the representation, and the resources used to create the representation. Referents were coded into one of two main categories: **performance targets,** which include headings, altitudes, speeds, vertical speeds, and aircraft attitudes, and **geographic features,** which include terrain, landmarks, waypoints, airways, localizer, glideslope, runway environment, and runway and taxiway centerlines. We also coded the resources that were used to create the representation. The attributes here were **verbal** resources, which includes spoken words; **non-verbal** resources, which includes gestures, body orientation, eye gaze and head movement and consequential actions (Segal, 1994); **displays**, which includes flight instruments and documents that were coordinated with the representation; and any **objects** or conditions outside the airplane that were coordinated with the representation. We also coded gestures as **iconic** (representing a spatial concept) and **indexical** (directing attention to objects or events). We noted and coded representations that were initiated by either pilot. We segmented the flights into phases: taxi-out, preflight, takeoff & climb, air work, approach vectors, ILS approach, landing, and taxi-in. We computed intermediate sums for the attributes across each phase of flight separately. It should be kept in mind that attributes of events are not mutually exclusive categories. For example, the vast majority of events make use of both verbal and non-verbal resources.

Figure 1. In this view from the HatCam, the instructor shows the student his pitch target for rotation during the takeoff.

Results

Frequency Counts

Table 1 shows the participants in each flight, the aircraft used, the number of spontaneously created representations of spatial relations, and the duration of the flight in minutes. On average, the participants create more than 4 spatial representations per minute.

Table 1. *The flights.*

Flight #	Student #	Instructor	Aircraft	Representations	Duration
1	1	F	CE-500	189	64
2	2	M	CE-525	412	87
3	3	M	CE-500	240	75
4	3	F	CE-500	312	40
Total				1153	266

Additionally, every video contained a section or sections where either the video or audio feed was lost temporarily. Therefore, the number of spatial representations is undoubtedly underreported within this study. We estimate that these events account for fewer than half of the communicative events generated in the flight overall.

At the beginning of the paper we noted that real-world meaning making tends to be multimodal in the sense that more than one expressive mode is utilized. Examining our data we see that 727 of the 1153 representations spontaneously created by instructor and student utilize a combination of verbal and non-verbal resources. This constitutes 63% of events and demonstrates the importance of *multimodality* of conceptualization in this activity. Every event that utilizes non-verbal resources relies on the fact that the two actors' bodies are co-present in a culturally meaningful space. In our corpus, that is 772 of 1153 events. This is 67% of the events and this large fraction indicates how fully *embodied* the activity is. 910 out of 1153 or 78% of the events incorporate an object or event that is present in the visible environment as an element of the representation. This demonstrates how profoundly *situated* the activity is. The majority of the spontaneously generated representations of spatial relations in this flight are multimodal, embodied, and situated.

Instructor/Student comparisons

Across all phases of flight, instructors make more than 3 times as many representations of spatial relations as students 877/266. This is probably driven by three factors: 1) The instructor role comes with an expectation of creating more representations of everything, 2) the demands of flying the airplane on cognitive resources make it more difficult for students to create representations, and 3) the creation of verbal representations is more costly in cognitive resources for the two foreign students than for the one American student.

Resource limitations

The ratio of student to instructor production of spatial representations was higher while the plane was on the ground vs. in the air. Across all flights, students created 37% of the total spatial representations while on the ground vs. 24% while in the air. It is not surprising that the student's rates of production of representations that use the body decreased from the pre-flight to the flying phases as student's hands were occupied controlling the airplane when hand-flying. However, there was also a sharp decrease in verbal representations as well. In fact, in flight student #1 incorporated verbal resources in the creation of spatial representations 13 times and incorporated non-verbal resources 17 times. Thus, even though the hands were occupied, the student still used his non-verbal resources more than verbal resources in flight. The typical non-verbal event here was a consequential action (setting the heading bug) rather than a gesture. We believe that this is due to the increased workload for the student in flight and to the fact that composing a meaningful action is cognitively less expensive for this student than composing an utterance in English.

Limitations on cognitive resources need not be a one-way causal route from body to mental. Ebbatson, Harris, & Jarvis (2007)investigated pilots attempting to assess crosswind components from the information provided by ATC. They report, "the mental arithmetic associated with calculating the runway crosswind impaired flying performance." Competition among tasks for cognitive resources was an issue for instructor F as well as for student #1. While on the final approach, the approach controller handed the airplane off to the tower controller. While the instructor was waiting for a pause in the tower radio traffic to check in with the tower, the student asked her if 600 feet per minute is a good descent rate to track the glideslope. It's a good question, but because she was waiting for a chance to speak, she did not want to begin a verbal exchange with the student. She pointed to the glideslope indication (on G/S), then to the vertical speed (-600 fpm), then back to the glideslope indication. In the post flight review of the video, the instructor commented that the student choosing to ask her a question while she was waiting to check in, with the tower controller reveals that student's lack of general situation awareness. The reduction in the rate of production of speech in flight might be more than simply a matter of resource limitations. It could also be that with the hands occupied on the yoke and thrust levers, talk is less likely. Rauscher, Krauss, and Chen (1996) found that "preventing speakers from gesturing adversely affected their ability to produce fluent speech when the content was spatial." Other studies show that restricting gesture reduces verbal abilities (Frick-Hornby & Guttentag, 1998; Rime, Schiaratura, Hupet, & Ghysselinckx, 1984).

Relations among gesture, space, and talk

By far the most common type of event observed in this activity arises when the instructor combines a verbalization with a gesture to a flight instrument. In these cases, the meaning of the event is established by the mutually constitutive relations among talk, gesture, and local space (Hutchins & Palen, 1997). A clear example of this happened during student #1's takeoff roll. The instructor called, "V1, and Rotate!" After a two-second pause in which the student applied some back pressure to the yoke, but not enough to lift the nose wheel off the runway, the instructor said, “Pull back. Ten degrees nose up.” While saying, “Ten degrees nose up” she pointed to the student’s attitude indicator to show him where to look to see the desired pitch attitude (See figure 1). The meaning of this indexical gesture, the pointing as a director of attention, is established by its coupling to the environment (Goodwin, 2000) in this case by its placement on the attitude indicator. The prevalence of indexical gestures that direct attention in and around the airplane is not surprising. Knowing where to look, when to look, and what to see when looking, are key skills in flying any airplane.

Discussion

The value of our two-airplane, three-student, two-instructor analysis is not to make claims about the differences among the cases. Rather, we are impressed by the overwhelming similarity across the cases. No matter the gender or nationality of the instructor or student, no matter the level of flying experience (250 hrs vs. 2000 hrs vs. 20000 hrs), no matter the airplane used, no matter the sort of flight (first flight vs. second, where the second includes a V1 cut and more instrument approaches), all participants (instructors and students) made extensive use of their bodies in constructing and reasoning about SA. Of course, there may be differences across these independent variables in the fine details of the way the body is used, but that is not something we can demonstrate with the data in hand. Everyone believes that SA is an important factor of every flight for every pilot worldwide. We agree. But we also believe that the establishment, expression, and maintenance of SA are embodied cognitive processes. This shows up also in the observations made in the Boeing sponsored project conducted by the first author of this paper. That project, has made in-flight observations of 70 segments of revenue flight with five different airlines based in 4 nations (Japan, New Zealand, Brazil, Mexico), operating in four languages (Japanese, English, Portuguese, Spanish), flown by a total of 64 pilots. Video data on an additional 26 pilots from the participating airlines flying a total of 50 hrs in high-fidelity flight simulators has been collected and analyzed. Those data show a similar pattern of use of the body to construct SA (Hutchins & Nomura, in press; Hutchins, Nomura, & Holder, 2006; Nomura & Hutchins, 2007). Still, embodiment does not yet have a central role in the understanding of SA. We suspect that one reason for this is that the uses of the body are largely unconscious – both in production and in interpretation. As such it may seem unlikely that interventions could change people’s behavior much. Furthermore, making the role of the body visible to analysis requires special equipment and techniques.

We are fully aware of the limitation of a study based on a small sample of complex events. In spite of the uncontrolled sources of variability noted in the methods section, the growing literature in embodied, situated, distributed cognition leads us to believe that many of our observations will generalize to other settings in which two or more actors jointly engage in consequential activity. Our analysis demonstrates that this type of flight training is profoundly embodied, multimodal, and situated. We believe that this is a central fact about flight instruction as it occurs in actual flight. Much of flight training concerns the domestication of attention: knowing where to look and what to see when looking there. This is an embodied skill. The representations we observed were tightly integrated with the resources provided by bodies located side-by-side in a complex material setting. These representations fluidly integrated observable with imagined aspects of spatial situation. The meanings of the representations emerged from the mutual elaboration of bodily motion, talk, and local space. This process of mutual elaboration supported the disambiguation of partial representations – including those that may have been due to limited competence in the English language. The observed representations of spatial situation integrated multiple, overlapping, fluidly shifting frames of reference.

In the near future, we are interested in tracking changes in these patterns through the training process. Will a student generate more representations of spatial situation as competence increases? Will the kinds of representations used by student or instructor change? Are certain gestures consistent among different instructors? We are also interested in the relationship between flight instruction as it occurs in an actual airplane and flight instruction in a high-fidelity simulator. Our observations here lead us to believe that with two students in the pilot seats and the instructor at a simulator operator station behind the students, the composition of representations of spatial relations will be very different. We expect to be able to do a comparison study in a high-fidelity simulator in the coming year.

Our preliminary findings lead us to believe that it will not be possible to understand teamwork, situation awareness, decision making, or communication without attending to how people use their bodies in the flight deck.

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