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How role assignment impacts decision-making in high-risk environments: evidence from eye-tracking in aviation

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Abstract

Adequate monitoring of automated systems is an essential aspect of procedure compliance, protective behaviour, and appropriate decisions in ultra-safe environments. In the air transport industry, the distribution of roles in a flight crew – Pilot Flying vs. Pilot Monitoring – reflects the importance of this task. Little is known about how pilot role assignment impacts monitoring behaviour and subsequent decision-making. We designed a field study where 62 airline pilots equipped with portable eye-trackers had to make a dynamic decision during approach in the airline's full-flight simulator. At a behavioural level, pilot role assignment (Pilot Flying vs. Pilot Monitoring) influenced decision time irrespective of rank (Captain vs. First Officer), with later decisions for the Pilot Monitoring. Eye-tracking results provided evidence that pilot role assignment rather than rank impacted fixations on choice-relevant information, with more fixations by the Pilot Monitoring. Overall, pilots' fixations on choice-relevant information could predict decision-making. We discuss implications for the optimal combination of role assignment and hierarchical rank.

Keywords

Aviation; monitoring; team role; decision-making; eye-tracking

1. Introduction

From nuclear power to medical surgery and aviation, operators have to make critical decisions in dynamic and uncertain environments (Dekker, 2003; Klein, 2008). In commercial aviation, for example, the pilot's ability to make "good decisions" is considered as skill acquired through intensive training in a highly-procedural environment (Kaempff & Klein, 1994). Despite the existence of procedures and intensive repetition, local, adaptive judgment in particular situations is required (Dekker, 2003). An important element of every decision in standard decision-making models is that the decision-maker has access to decision-relevant cues – frequently described as *representation* of options (Rangel, Camerer, & Montague, 2008) or *recognition* of cues (Klein, 2008). Monitoring – defined as repeated assessment of the current status of the system – is vital for detecting, evaluating, and recognising unexpected changes in many domains with high safety standards from the nuclear industry to automobiles and air traffic control (Brookhuis, De Waard, & Fairclough, 2003; Metzger & Parasuraman, 2001). The definition of monitoring is linked to the first main component of situational awareness "the ability to notice changes" (Endsley, 1995). This ability is essential for appropriate decision-making. In aviation, "Monitoring Matters" is the statement of numerous aviation authorities,

airlines, and aircraft manufacturers (CAA, 2013; Flight Safety Foundation, 2014). Poor monitoring has been identified as one of the major reasons of recent loss of control events (Dutch Safety Board, 2010; NTSB, 2013a, 2013b). Monitoring of cockpit instruments can be assessed by an individual's visual attention distribution. For instance, cognitive psychologists have established a positive correlation between visual attention and decision-making (Deubel & Schneider, 1996). Prior research has pointed out that the use of eye-tracking could give insights into operators' scanning patterns (Duchowski, 2002) – particularly in airline pilots (Dehais, Behrend, Peysakhovich, Causse, & Wickens, 2017; Sarter, Mumaw, & Wickens, 2007; Schriver, Morrow, Wickens, & Talleur, 2008). Schriver et al. (2008) showed expertise differences in pilots' visual strategies during decision-making. Some studies interestingly pointed to the lack of compliance between operational procedures and pilots' eye gaze (BEA, 2013; Björklund, Alfredson, & Dekker, 2006). More recently, Reynal, Rister, Scannella, Wickens, and Dehais (2017) demonstrated that pilots' gaze pattern was indicative of their upcoming landing decision in a simulated scenario.

Little research has focused on how pilot role assignment (who does what within a team) may influence cockpit behavior (Jentsch, Barnett, Bowers, & Salas, 1999). In airlines, a two person crew is composed of a Captain, the higher-rank member holding the legal responsibility and decision power, and a First Officer, the lower-rank member occupying the right hand seat in the cockpit. Besides this formal hierarchical differentiation, pilots can occupy two different roles: Pilot Flying (in control of flying the airplane) or Pilot Monitoring (in control of monitoring the flight management, double checking Pilot Flying's actions, and communication). Role change or task sharing is defined before the commencement of every leg of a trip (Flight Safety Foundation, 2014). Whereas the Pilot Flying task is perceived as active, the Pilot Monitoring (historically called "Pilot Non-Flying") is perceived as passive. However, the necessity of monitoring has reinforced the definition of pilots' roles in the cockpit, emphasising the importance of an active Pilot Monitoring role regarding the detection of flight parameter deviations (CAA, 2013).

Little is known, however, about how pilot role assignment influences pilot decision-making under uncertainty. In order to address this issue, we designed a flight scenario in a full-flight simulator in which crews equipped with portable eye-trackers had to make a landing decision based on ambiguous wind information displayed on flight instruments in the cockpit. Pilots could make the decision to either continue the approach and land the aircraft or to abort it (in aeronautical terms "perform a go-around"). We chose the final approach phase since it has been identified as the most demanding (Lee & Liu, 2003) and hazardous (U.S. Department of Transportation, 2015) flight phase in which monitoring is an important element (BEA, 2013). At a behavioural level, one hypothesis – according to company procedures – could be that pilot role is not related to decision power and has no influence on decision-making. In addition, the decision to perform a go-around can be taken by both crewmembers in the participating airline. However, we consider that the detection of decision-relevant

information on flight instruments is part of decision-making. Thus, at an eye-tracking level, one hypothesis – based on task sharing – might be that the Pilot Flying is concentrated on flying the airplane while having less cognitive resources available for the detection of decision-relevant information than the Pilot Monitoring. Another hypothesis could be that both pilots monitor the flight parameters in the same way, double-checking each others’ activities. To the author’s knowledge, few studies have attempted to simultaneously measure both Pilot Flying and Pilot Monitoring’s eye movements in the cockpit (Björklund et al., 2006; Reynal et al., 2017; Dehais et al., 2017). Moreover, the researchers had access to a representative and relatively large number of commercial airline pilots.

2. Materials and Methods

2.1 Participants

Overall, 62 airline pilots (age range 29-65 years, experience range 3,000-23,000 flight hours) from the same airline participated in the study. They were qualified on either Airbus A320 (short-haul flights) or A340 (long-haul flights). Table 1 presents the characteristics of this sample size. There were no significant age ($t(60) = 0.25, p = 0.98$), flight experience ($t(60) = -0.48, p = 0.63$), or rank differences ($\chi^2(1, 62) = 0.0, p = 1.0$) between both groups: Pilot Flying and Pilot Monitoring. The rostering department of an airline randomly chose these pilots from the pilot pool. Random assignment is the normal process for creating pilots’ flight schedules. Next, we emailed these pilots, inviting them to participate in this study. Pilots were paid for their voluntary participation by their company. Confidentiality was guaranteed. All participants gave written informed consent. Crews were not familiar with each other. This reflects the most common situation in a major airline with a large number of pilots where it is rare that crews know each other.

Table 1. Demographic characteristics of the sample size

<i>Participants (n)</i>	<i>Gender, Male</i>	<i>Age, years</i>	<i>Rank, Captain</i>	<i>Flight experience, hours</i>
	<i>% (n)</i>	<i>M (SD)</i>	<i>% (n)</i>	<i>M (SD)</i>
All (62)	92 (57)	46.2 (10.2)	52% (32)	11034 (4255)
Pilot Flying (31)	90 (28)	46.2 (7.9)	52% (16)	10771 (4441)
Pilot Monitoring (31)	94 (29)	46.1 (12.3)	52% (16)	11297 (4118)

2.2 Procedure

Prior to the empirical study in the company’s full-flight simulator, each participant signed a consent form and was briefed on the study’s aim: understanding pilots’ visual attention distribution during

flight, without specifying fixations on wind information under conflict during final approach. As in regular simulator training, pilots are not informed in advance about the whole scenario and its purpose. We aimed to observe pilot behaviour in the most natural context. Next, the volunteer pilot was taken to the full-flight simulator where he/she took his habitual crew position in the cockpit (First Officer right seat, Captain left seat). The volunteer participant was equipped with a portable eye-tracker. A confederate pilot with the opposite rank joined the participant. In order to minimise individual differences in pair work, the confederate pilot was briefed to behave as neutrally as possible without being proactive in action taking. The approach scenario of 15 minutes started as soon as crew agreed and finished their approach briefing. The pilots performed further approaches which were not subject to the current research. Upon completion of the scenario, the experimenters accompanied the volunteer participant into a debriefing room where he/she gave demographic information and responded to questions regarding the flight scenario. In the end, we debriefed all participants on our interest in decision-making under uncertainty.

Figure 1 illustrates the protocol timeline.

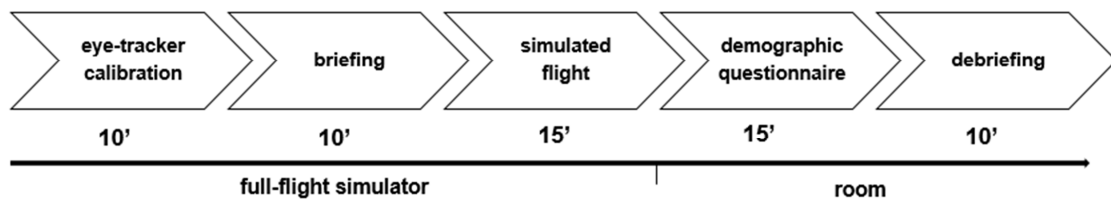


Figure 1. Protocol timeline.

2.3 Apparatus

Flight simulator. To create a realistic environment, the study was conducted in the airline's two Airbus-type full-flight simulators (FFS Level D): an A320-214 (CAE visual system and motion system) and an A340-300 device (CAE visual system and Thomson motion system).

Eye-tracking system. Participants' fixation patterns were recorded at 100 Hz using the Tobii Pro Glasses 2 wearable eye-trackers. Additionally, the head unit of the eye-trackers captured the participants' visual scene in real time (camera) as well as verbal communications (microphone). Eye fixations were mapped on a reference image including the major flight instruments. One area of interest, i.e. the wind indication on the Navigation Display, was identified (see Figure 2). According to the Tobii Pro Lab Analysis Tool, we used the Tobii I-VT (Fixation) filter: the velocity calculator has a window length of 20ms, the threshold of the fixation classifier is 30 degrees/second and the minimum fixation duration is 60ms. The I-VT (Velocity-Threshold identification fixation filter) is based on the

work by Komogortsev, Gobert, Jayarathna, Koh, and Gowda (2010) as well as Salvucci and Goldberg (2000).

2.4 Scenario

In collaboration with the participating airline, we designed a scenario which was programmed by a flight instructor. Each participant performed the same approach. The level of automation was left to the crew's discretion. However, the flight crew had to disconnect the autopilot before 160ft above ground level, since the approach was an Instrumental Landing System (ILS) category (CAT) 1. During the approach, a computer voice provided live air traffic control communications of other airplanes landing on the same runway.



Figure 2. An example of the reference image with the area of interest (wind). Analyses were focused on the decision relevant item in the cockpit.

We aimed to create an uncertain decision situation by manipulating wind information in the cockpit. According to the Airbus Aircraft Flight Manual, both aircrafts (A320 and A340) were limited to 10 knots tailwind at landing. The flight crew must respect this limitation. While Air Traffic Control indicated a tailwind within aircraft limitations, cockpit information (Navigation Display) displayed a tailwind out of aircraft limitations. This is a frequent operational situation for pilots since wind information is elaborated differently: Air Traffic Control information is based on wind measurement on the ground (two minutes mean value). Aircraft displays a computed real-time wind at actual flight level. Air Traffic Control information is verbally communicated to crew, whereas the pilot has to detect or monitor the aircraft information.

Participants (half PF, half PM) performed an approach at Munich Airport, starting at flight level 150. This airport was chosen due to the long runway length of 4000 meters. The weather was rainy and the runway wet. Air Traffic Control cleared the aircraft for the ILS CAT 1 approach runway 08L. The ceiling was at 500ft. At 700ft above ground level, the wind turned into an illegitimate tailwind (220/17 knots) on aircraft displays, whereas wind information given by Air Traffic Control remained unchanged.

Pilots are forced to make a decision since according to company procedures, they are allowed to continue the approach but also always might choose to perform a go-around. The scenario lasted around 15 minutes.

2.5 Measures

Pilot role. Pilots were divided into two groups: Pilot Flying versus Pilot Monitoring. In order to represent equally rank, half of the Pilot Flying were Captains, half of them First Officers (vice versa for Pilot Monitoring). See Table 1 for more details.

Flight experience. Pilots indicated their flight experience in number of flight hours (see Table 1).

Decision. Pilots responses (continue the approach or perform a go-around) were recorded by the experimenter who was present in each simulator scenario. According to role and company procedures, the Pilot Flying executes the go-around since he/she flies the airplane. When the Pilot Monitoring wishes to perform a go-around, he makes the call-out *Go-around* which the Pilot Flying has to follow and automatically executes. In this study, the call-out *Go-around* was counted as the decision to perform a go-around when the participating pilot was Pilot Monitoring. When the participating pilot was Pilot Flying, the go-around execution was counted as the decision to perform a go-around.

Information acquisition / gaze data. The decision-relevant information in the cockpit is displayed on the navigation display: the wind (see Figure 2). We measured the number of eye fixations on the wind indication during final approach. For each participant, we analysed ocular behaviour for the following two phases: first between 1,000ft and 200ft (from stabilisation height to decision height) and second between 200ft and 100ft / decision (from decision height to go-around decision). The stabilisation height and the decision height are two important decision moments during approach. At the stabilisation height, the stabilisation criteria (technical values such as the correct speed, etc.) have to be met in order to continue the approach. Otherwise, a go-around has to be performed. The decision height is a specific altitude and decision moment where the pilot has to see the runway. If the required visual references are not acquired, a go-around should be performed according to procedures (see Figure 3 for illustration).

2.6 Eye-tracking data quality and exclusion

The pilots' gaze data was verified in order to ensure data-availability quality criteria. Overall pupil detection quality was good ($M = 87\%$). We had to exclude five from the 62 participants for the eye-tracking analyses due to recording issues during the simulator scenario.

3 Results

3.1 Behavioural results

Overall, 47% of all pilots made the decision to perform a go-around. Among these pilots, almost all (95%) decided under 200ft Above Ground Level (AGL), i.e., approximately at 100ft (M reaction time after decision height = 8,32 sec, SD reaction time after decision height = 4,2 sec). During debriefing, most pilots reported that their aim was to delay the decision as long as possible in order to see if the wind on the navigation display would calm down close to ground. Figure 3 illustrates the scenario timeline with the pilots' key decision moments (AGL) during approach.

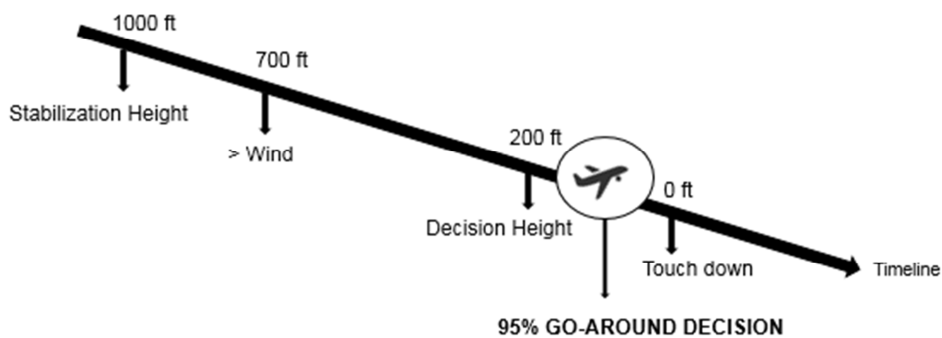
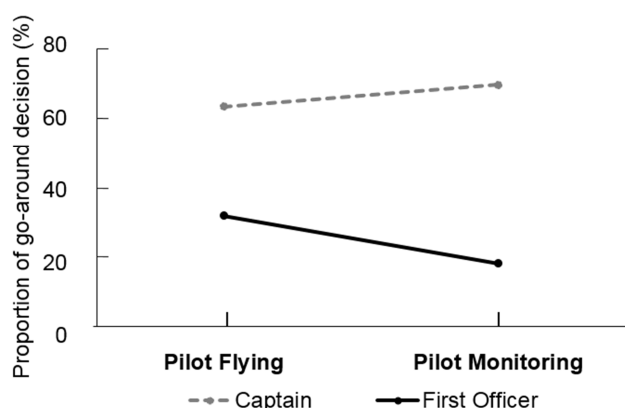


Figure 3. Scenario timeline with pilots' key decision moments during approach.

Chi-square test showed no differences between pilots' roles (Pilot Flying vs. Pilot Monitoring) and decision (continue the approach vs. go-around); $\chi^2(1, n = 62) = 0.065, p = .79$. Additionally, there were no significant decision differences between both Captains and First Officers operating as Pilot Flying ($\chi^2(1, n = 62) = 2.64, p = .10$). However, Fisher's Exact test found significant differences between the Captains and First Officers working as Pilot Monitoring ($p = .011$, two-tailed), i.e., Captains as Pilot Monitoring asked more often for a go-around than First Officers as Pilot Monitoring (see Figure 4). Overall, chi-square test showed an effect of rank (Captain vs. First Officer) on decision-making ($\chi^2(1, n = 62) = 9.44, p = .002, \phi = .39$), i.e., Captains



performed or asked more often for a go-around than First Officers.

Figure 4. Pilot Flyings' and Pilot Monitorings' proportion of go-around decisions (%) as Captain and First Officer.

Next, a t-test was conducted in order to understand the influence of pilots' role on decision reaction time below the decision height (see Figure 5). The Pilot Flying made a decision earlier ($M = 6.37$, $SD = 3.98$) than the Pilot Monitoring ($M = 9.17$, $SD = 4.71$); $t(52) = -2.36$, $p = .022$, $d = -0.65$. Rank had no influence on the decision moment ($t(52) = -.482$, $p < .631$).

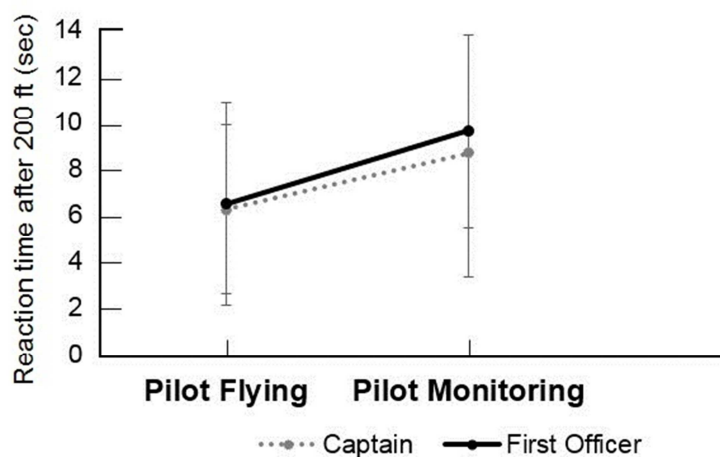


Figure 5. Pilot Flyings' and Pilot Monitorings' proportion of reaction times after 200 ft (sec) as Captain and First Officer.

3.2 Eye-tracking results

The Pearson product-moment correlation coefficient was computed to assess the relationship between the proportion of decision-relevant wind fixations and pilots' flight experience. The analysis disclosed a weak and negative correlation between the two variables, $r = -0.29$, $n = 57$, $p = .031$. A scatterplot summarises these results (see Figure 6). An increased proportion of wind fixations was correlated with less flight experience.

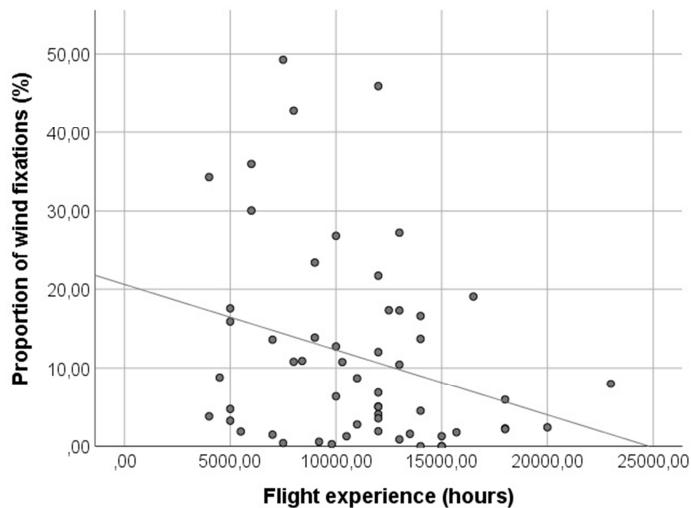


Figure 6. Simple scatter with fit line of the proportion of wind fixations (%) between 1000ft - decision and flight hours

A 2x2 between-group analysis of covariance was conducted to assess the impact of pilot role on the proportion of decision-relevant wind information for go-around decisions between 1000ft and 200ft whilst controlling for flight experience. The independent variables were pilot role – Pilot Flying vs. Pilot Monitoring – and the decision – go-around or landing. The dependent variables was the proportion of wind fixations during 1000ft and 200ft. The covariate was flight hours. Levene’s test and normality checks were carried out and met. There were significant differences in proportion of wind fixations between role ($F(1, 52) = 6.68, p = .013, \eta_p^2 = .114$) and decision ($F(1, 52) = 4.12, p = .048, \eta_p^2 = .073$). Post hoc tests showed a tendency that go-around pilots fixed more often on the wind than landing pilots ($p = .048$). The group Pilot Monitoring fixed more often the wind than the group Pilot Flying ($p = .013$). The covariate, flight hours, was significantly related to the participants proportion of wind fixations, ($F(1, 52) = 8.18, p = .006, \eta_p^2 = .136$).

Next, we performed another 2x2 between-group analysis of covariance to test the impact of pilot role on the proportion of decision-relevant information for go-around or landing decisions between 200ft and the go-around decision whilst controlling for flight hours. Levene’s test and normality checks were carried out and met. We confirmed significant differences in proportion of wind fixations between role ($F(1, 52) = 27.13, p = .000, \eta_p^2 = .343$) and decision ($F(1, 52) = 4.09, p = .048, \eta_p^2 = .073$). However, flight hours were not significantly related to the participants’ proportion of wind fixations ($F(1, 52) = 3.15, p = .082, \eta_p^2 = .057$). Pairwise comparisons showed a tendency that go-around pilots fixed more often on the wind than landing pilots ($p = .048$). The group Pilot Monitoring fixed more often on the wind than the group Pilot Flying ($p = .000$). There was no interaction effect of pilot role and pilot decision ($F(1, 52) = 0.10, p = .753, \eta_p^2 = .002$). Figure 7 shows both analyses of covariance between 1000ft and 200ft, and 200ft and the decision.

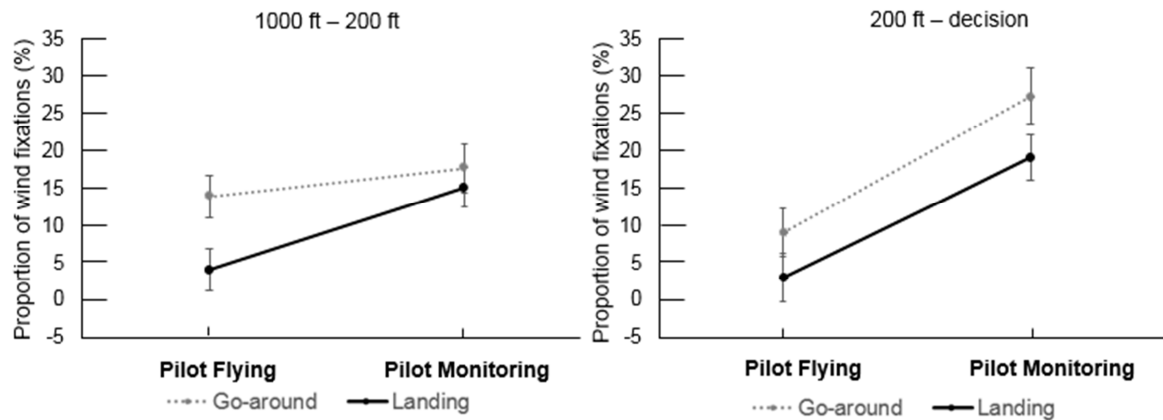


Figure 7. Pilot Flyings' and Pilot Monitorings' proportion of go-around decisions (%) as when performing a go-around or continuing the approach between 1000ft and 200ft on the left and between 200ft and the go-around decision on the right.

Excluding the covariate flight hours from the 2x2 between-group analysis variance between 200ft and the decision moment, the main effect of decision disappeared ($F(1, 53) = 2.17, p = .147, \eta_p^2 = .039$), whereas the influence of role persisted ($F(1, 53) = 25.58, p = .000, \eta_p^2 = .326$). Pairwise comparisons confirmed that the Pilot Monitoring fixed more on the wind ($M = 22.95, SD = 2.45$) than the Pilot Flying ($M = 5.89, SD = 2.30$), $p = .000$.

4 Discussion

4.1 General discussion

This research experimentally tested the influence of pilot role assignment – Pilot Flying versus Pilot Monitoring – on decision making under uncertainty in a high-fidelity simulation with eye-tracking. Behavioural results showed that half of the pilots decided to continue the approach, whereas the other half decided to perform a go-around. Pilot role assignment irrespective of rank impacted the go-around decision moment: the Pilot Flying performed a go-around earlier than the Pilot Monitoring. Eye-tracking results provided evidence that pilot role assignment rather than rank impacted fixations on the decision-relevant information, with more fixation by the Pilot Monitoring. Overall, go-around pilots – when integrating their flight experience – fixed more often on decision-relevant information than landing pilots.

The fact that half of the pilots decided to continue the approach reflects and confirms the uncertain and binding decision character of this situation. Procedures – frequently defined operating rules – are developed in order to cope with complexity and unify behaviour in ultra-safe systems (Dahl, 2013; Dien, 2000) such as aviation (Goteman & Dekker, 2006). The majority of pilots made their go-around

decision below 200 ft – a few seconds before touch down. Pilots argued during debriefing that they delayed their decision in order to reconcile wind information at actual flight level (Navigation Display) with wind information on the ground (Air Traffic Control). According to procedures, a go-around decision could be explained by superior tailwind information on the Navigation Display which was out of limitations (human-machine interaction). By contrast, a landing decision could be explained by the Air Traffic Control’s wind information which was within aircraft limitations (human-human interaction). During debriefing, pilots categorised themselves in three different decision strategy groups: trusting entirely Air Traffic Control (e.g., “The Air Traffic Control wind counts; it is the legal wind”), trusting entirely the Navigation Display (e.g., “I completely trust my airplane”), or trusting and integrating both information in order to make a decision (e.g., “I consider both wind information. When doubting I take the strongest wind for any decision”). Figure 8 displays the three different options.

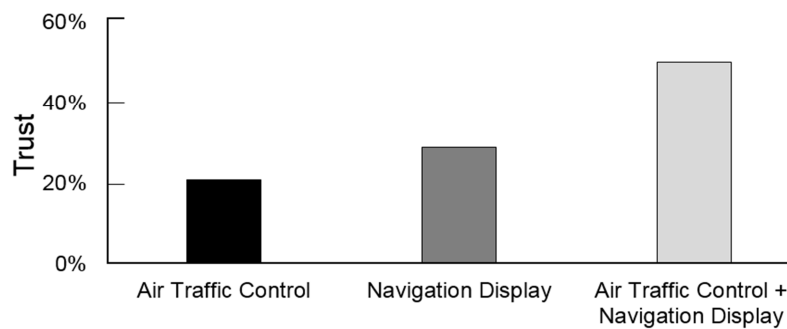


Figure 8. Pilots’ reported trust in Air Traffic Control, Navigation Display, or both Air Traffic Control and Navigation Display for decision making based on wind-relevant information.

These findings support the idea of previous research and safety analyses: procedures are prone to interpretation (Decker, 2003; Flight Safety Foundation, 2014). Lee and See (2004) argue that trust – an expectation towards a particular outcome – influences and guides reliance on systems and operators in order to better understand human-machine interaction. Dekker (2003) describes two models in order to better understand the trade-off between practice and theoretical guidelines in safety environments. Model 1 considers procedure application as best operation rule that ensures safety (e.g., stimulus - response). Model 2 defines procedure application as cognitive activity that requires judgment and adaptation to specific circumstances, in particular under uncertainty or novelty. While civil aviation is often cited as example for model 1 (Dekker 2003), our findings show practical examples of highly-trained individuals operating as both rule followers (model 1) and/or cognitive decision-makers (model 2).

Time pressure inhibites our reflective system rather than our reflexive system (Evans & Curtis-Holmes, 2005), i.e., under time pressure, it is easier to be a rule follower than a cognitive decision-

maker. During debriefing, pilots reported that communication between both crewmembers facilitated the decision-making process under time pressure. Since the final approach is a dynamic flight phase with high time pressure, pilots' experienced an easier decision-making process, when both pilots agreed on a common decision strategy during the briefing. An example of a verbatim of a Pilot Flying: "We have tail wind. In general, I use the Air Traffic Control wind. However, when you detect more than 13 knots tailwind on the Navigation Display, please let me know and we will perform a go-around." Sharing a common decision strategy between both pilots with in a clear briefing can help to take actions under time pressure.

As hypothesised and according to company procedures, we found that pilot role assignment had no influence on decision power: overall, both roles made the same amount of go-around and landing decisions. However, we found one distinctive difference: Captains as Pilot Monitorings asked for more go-arounds than First Officers as Pilot Monitorings. Our results confirm previous research regarding crew resource management (Helmreich, Merritt, & Wilhelm, 1999): a non-expert co-pilot is less inclined to question the Captain's actions when the latter is in command (Jentsch et al., 1999). A possible explanation from general aviation might be that novices have less decision-making confidence than experts (Wiggins & O'Hare, 1995).

Nevertheless, pilot role assignment influenced decision time irrespective of rank: the Pilot Flying performed a go-around earlier than the Pilot Monitoring. Qualitative video analyses showed that most pilots serving as Pilot Monitoring communicated technical wind information (e.g., wind speed in numbers and directions) to the Pilot Flying before making the call-out *Go-around*. One could argue that the Pilot Monitoring (not in control) wanted the Pilot Flying (in control) to perform the subsequent actions. The common understanding of the Pilot Monitoring is to detect and announce flight parameter deviations to the Pilot Flying (CAA, 2013).

Combining these behavioural results with our eye-tracking results, we found a predictive role of the Pilot Flying between 1,000ft and 200ft: the Pilot Monitoring spent nearly the same amount of time fixating on the wind regardless of the decision. However, the Pilot Flying spent approximately three times more on the Navigation Display if he/she decided to perform a go-around. *Did the Pilot Flying prepare his/her go-around decision?* One could argue that the Pilot Flying might have anticipated this decision while integrating the wind information. Interestingly, we observed the opposite between 200ft and the decision: a predictive role of the Pilot Monitoring was found. Here, the Pilot Flying spent almost the same amount of time fixating on the decision-relevant wind, whereas the Pilot Monitoring fixated most on the wind if he/she made the call-out *Go-around*. Indeed, the flight phase under 200ft is very dynamic. Many participants as Pilot Flying delegated the wind check to the Pilot Monitoring in order to concentrate on flying the aircraft (different cockpit instruments and outside world).

Overall, we showed that the Pilot Monitoring fixated more on the decision-relevant information than the Pilot Flying regardless of his/her decision. People look at elements in order to acquire information. Prior research from cognitive psychology has shown that fixations are related to visual attention and cognitive processing (Carrasco, 2011; Yarbus, 1967). Due to this task sharing, one could argue that the Pilot Monitoring might have more cognitive resources in order to acquire decision-relevant information. These results further suggest that the role of the Pilot Monitoring is essential for the communication of decision-relevant information (to the Pilot Flying) during final approach.

In addition, go-around pilots fixated more often on the wind information than landing pilots when integrating their flight experience. This result is reflected in previous research: people have the tendency to allocate more visual attention to decision-relevant information before decision-making (Glöckner & Herbold, 2011). Indeed, one could imagine that go-around pilots spent more attention on wind information on the Navigation Display than landing pilots who followed verbal Air Traffic Control instructions. Interestingly, more experienced pilots spent less time on decision-relevant wind information than less experienced pilots. Besides, previous research emphasised that pilots' expertise, measured by flight hours, can accelerate decision-making (Schriver et al., 2008) and is predictive of landing decision accuracy in general aviation (Causse, Dehais, Arexis, & Pastor, 2011). At a purely behavioural level, expertise reflects domain knowledge, which shapes, together with information acquisition, decision-making (Shanteau, 1992; Wiggins & O'Hare, 2003). For example, Bellenkes, Wickens, and Kramer (1997) argued that expert pilots are able to better direct their visual attention to flight-relevant information; it is possible that they might need less visual information in order to evaluate the situation.

4.2 Limitations

A first limitation of this study is that the Pilot Flying could choose to keep the autopilot until the decision height (200 ft). The level of automation is correlated with pilots' monitoring strategies and cognitive resources (Casner, 2009). Flying the airplane by hand without the use of automation induces high workload (Casner & Schooler, 2015) and may impair overall monitoring capacities (Haslbeck & Hoermann, 2016). Consequently, this might have introduced differences in visual scanning between the pilots who manually flew the approach versus the pilots who used the autopilot as long as possible. Although previous research has shown a strong relation between gaze direction and attention, it is not total. Indeed, it is possible to "look at something without seeing it" when cognitive resources are engaged by unrelated thoughts, communication within crew or with Air Traffic Control (Casner & Schooler, 2015; Strayer & Johnston, 2001). Einstein, McDaniel, Williford, Pagan, and Dismukes

(2003) showed that rapid attentional shifts (or task interruptions) could cause prospective memory impairments such as forgetting to recall a planned intention.

5 Conclusions and implications for flight safety

The objective of this field study was to better understand the influence of pilot role assignment on decision-making under uncertainty in commercial aviation. The scenario confirmed that procedures were prone to interpretation. Our findings indicated that the role of the Pilot Monitoring had significant influences on the Captain's vs. First Officers behaviour. Moreover, pilot role impacted the decision moment, with earlier decisions for the Pilot Flying. The eye-tracking results demonstrated that pilot role assignment influenced visual information acquisition: the Pilot Monitoring spent more time on decision-relevant information irrespective of the decision. When integrating pilots' flight experience, the percentage of fixations on the decision-relevant information predicted overall pilot decision-making. While previous findings have indicated several factors biasing landing decision such as economic pressure (Causse, Dehais, Péran, Sabatini, & Pastor, 2013), time pressure (Bearman, Paletz, Orasanu, & Brooks, 2009), proximity to final destination (Rhoda & Pawlak, 1999), overconfidence (Flight Safety Foundation, 2014), or perseveration for going home (Dehais et al, 2019), this study brings additional insights on landing decisions made under uncertainty in commercial aviation. In addition, it emphasises the utility of eye-tracking to better understanding pilots' scanning patterns. The high number of participants in a full-flight simulator is a strength of this study.

We suggest the following actions:

- In situations, that are not completely covered by procedures, a clear briefing between both pilots should be performed under low time pressure before starting the approach. This briefing might highlight predictable binding situations that may occur under high time pressure. For these particular cases, both pilots should clearly define and share a common decision strategy to facilitate the decision-making process under high time pressure.
- Training should emphasise the active role of the Pilot Monitoring (in particular for the First Officer) for decision-making.
- Training should value the role of the Pilot Monitoring for the detection of decision-relevant information and so the importance of sharing this information with the Pilot Flying.

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Legends

Figure 1. Protocol timeline.

Figure 2. An example of the reference image with the area of interest (wind). Analyses were focused on the decision relevant item in the cockpit.

Figure 3. Scenario timeline with pilots' key decision moments during approach.

Figure 4. Pilot Flyings' and Pilot Monitorings' proportion of go-around decisions (%) as Captain and First Officer.

Figure 5. Pilot Flyings' and Pilot Monitorings' proportion of reaction times after 200 ft (sec) as Captain and First Officer.

Figure 6. Simple scatter with fit line of the proportion of wind fixations (%) between 1000ft - decision and flight hours

Figure 7. Pilot Flyings' and Pilot Monitorings' proportion of go-around decisions (%) as when performing a go-around or continuing the approach between 1000ft and 200ft on the left and between 200ft and the go-around decision on the right.

Figure 8. Pilots' reported trust in Air Traffic Control, Navigation Display, or both Air Traffic Control and Navigation Display for decision making based on wind-relevant information.