

Pilots' Decision-Making under High Workload: Recognition-Primed or Not – An Engineering Point of View

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The objective of this study is to analyse pilots' decision-making behaviour in terms of naturalistic decision-making. In line with the highly experienced group of pilots ($n = 120$), recognition-primed decisions are expected to dominate. In a full-flight simulator experiment, with two groups of pilots (short-haul and long-haul pilots) with different levels of practice and training, we were able to show that only about one-third of the pilots make recognition-primed decisions. Results may indicate that the current training practice helps pilots to handle foreseeable problems very well, yet does not support pilots in ambivalent and new decision-making situations. Based on these findings, we recommend the incorporation of more unforeseen events in recurrent training simulator missions to train pilots in handling unknown situations.

Practitioner Summary: The results from a flight-simulator study showed that pilots' decision-making is more analytical than recognition-primed. A possible reason for this could be the pressure for justification, or simply that pilots cannot use their experience in unforeseen situations. Hence, training should include more unforeseen events.

Keywords: recognition-primed decision (RPD), naturalistic decision-making (NDM), flight-simulator, crew resource management, FOR-DEC

1. Introduction

Checklists and procedures were introduced in the aviation domain decades ago to enhance different aspects of safety, standardisation and human reliability (e.g. Degani & Wiener, 1990). Although the reliability of the whole aviation system has been greatly improved during the last decades, in some rare cases, pilots have had to make decisions that required going beyond prescribed procedures. They are sometimes faced with situations which cannot be managed by applying procedures or analytical decision-making. There are two recent incidents exemplifying this very well: US Airways Flight 1549 and Qantas Flight 32.

When the crew of US Airways Flight 1549 took off from LaGuardia, they hit a flock of birds, resulting in the loss of both engines (National Transportation Safety Board, 2010). In this extremely time-critical scenario, the Captain instinctively decided not to follow the procedures, but to land on the Hudson. Although he did not follow the procedure, it seems he was able to rely on his experience and to make a good decision that led to the survival of all the passengers. The conditions of this situation such as time pressure, the high-risk environment and the pilots as domain specific experts, assign this scenario as framework for natural decision making (cf. Orasanu & Connolly, 1993). The crew of Qantas Flight 32 was faced with an uncontained engine failure shortly after take-off (Australian Transport Safety Bureau, 2013). The five pilots on board of the Airbus A380 then would have had to work through more than 100 procedures but, at one point, decided to stop the trouble-shooting and landed. This might also be an example for a natural decision making situation. The question arises how experience can support pilots' decision-making in unforeseen and critical situations.

In current training, pilots mainly develop experience in terms of checklist or procedure-handling to solve problems analytically. Consequently, pilots can rely on their experience as long as no ambivalent, intermittent or multiple influencing factors are present. The question arises as to what extent pilots are able to develop solid experience to recognise patterns also in ambivalent, unforeseen, and new situations. In other words, how do pilots become competent in dealing with unclear situations if the training emphasis lies on pre-defined situations and procedure application? What made the pilots of the US Airways Flight 1549 and Qantas Flight 32 deviate from their analytical behaviour and adherence to procedures? Consequently, the question arises whether pilots can make effective use of their experience in relevant decision situations.

It must be pointed out that the intention of this paper is neither to question the necessity of procedures and checklists, nor to evaluate different decision-making approaches with regard to their outcome; this analysis aims to understand how pilots actually come to their decisions and how naturalistic decision-making might be a valuable training aspect.

2. Literature

The naturalistic decision-making (NDM) field of research considers intuition as a reliable source for experts' decision-making (Klein, 1993a). While this approach was introduced back in 1946 when analysing chess masters' behaviour (De Groot, 1978), Gary Klein represents the NDM research field nowadays, cf. Klein (1993a). Chase and Simon (1973) found that chess masters were able to recognise different sets of chessmen patterns and were thereby able to see the best manoeuvres. In contrast to the NDM approach, the heuristic and biases approach (HB) finds experts' decision-making critical. Meehl (1954) found that the decision-making performance of clinical psychologists was worse than predictions from statistical models. Nowadays, Daniel Kahnemann has showed that experts, although they receive training, often base their decision on wrong assumptions (Kahnemann, 2011). Kahnemann and Klein (2009) clarified under which circumstances experience can be established, and stated that this ability also depends on particular personal factors. Furthermore, several studies indicate that factors, such as engagement or motivation, influence the establishment of skilled intuition (Kahnemann & Klein, 2009). They pointed out another very important factor influencing skilled intuition is creative intuition – the ability to find valid patterns in memory.

The NDM approach places emphasis on situations which are affected by time pressure, domain-specific experience of the decision-makers, high-risk environments, badly-structured decision problems and dynamic situations, as well as organisational goals and norms (Cannon-Bowers, Salas, & Pruitt, 1996). Klein (1993a) formed the term, the *recognition primed-decision model* (RPD), which describes experts' strategies to make fast decisions in highly critical situations. He found that experienced firefighters, for example, did not compare different options in critical situations, but were able to recognise specific patterns and were thus able to react appropriately (Klein, 1993a). In fact, experts evaluate the first option that comes into their mind for its feasibility; if the option seems feasible, they choose it, if it does not seem feasible, they reject this option and evaluate the next option which comes into their mind (Klein, 1999). To make recognition-primed decisions, the decision-maker has to have had the opportunity to gain experience in the specific domain, in order to recognise the stimulus and to act appropriately. As humans do sometimes make poor decisions, in the aviation domain, human decisions are often supported by automation and standardisation (Wiener, 1995). When it comes to the point where pilots have to make a decision, specific formalisms can be applied to assist the pilots in structured decision-making (Orasanu, 1995). As one example of such prescriptive techniques, the FOR-DEC model (Hoermann, 1995) became popular in German airlines. FOR-DEC stands for the steps, "Facts – Options – Risks/Benefits – Decision – Execution – Check". While these analytical models work perfectly in abnormal situations without huge time pressure, they reach their limits when pilots are faced with extreme time pressure. Simpson (2001) found that, in such situations, RPD decisions led to better performance than analytical approaches. With pilots working in a highly dynamic environment, the question arises how they make their decisions and how their performance is assessed when being faced with complex and time-critical situations.

3. Research Questions

RQ 1: How do pilots make decisions? What is the proportion of recognition-primed decisions (RPD) and non-recognition-primed decisions (nRPD)?

H1.1: Experience positively influences the probability of pilots using RPD.

H1.2: Cognitive skills for generating associations and combining relevant information, positively influences the probability of pilots using RPD.

RQ 2: How strongly do pilots benefit from their subjectively-perceived experience? Does this estimation distinguish between RPD and nRPD pilots?

RQ 3: How often are pilots faced with uncertainties during flights? Does this frequency allow the distinguishing between RPD and nRPD pilots?

RQ 4: How are pilots' non-technical skills rated by an instructor pilot? Is there a difference between RPD and nRPD pilots?

4. Method

4.1. Test Design

Based on the stated research questions, the test design, as visualised in Figure 1, was developed. The experience and the ability for creative problem-solving therein predict the probability of RPD; the decision-making processes differs between recognition-primed decisions (RPD) and those which cannot be assigned to RPD – these are labelled as non-recognition-primed (nRPD). Based on their decision-making process, the pilots are grouped and the differences in respect of their perceived benefit from experience, their uncertainties and the instructor estimations are analysed.

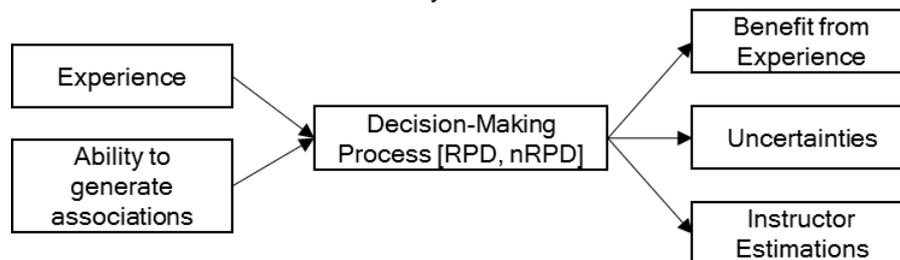


Figure 1. Visualisation of test design.

4.2. Measurement

4.2.1. Participants

In total, 120 randomly selected type-rated pilots, all from the same airline, forming 60 crews (30 short-haul and 30 long-haul crews), were elected to fly a full flight-simulator scenario during altogether 20 simulator shifts. Instead of having volunteers, the participants were scheduled by the airline based on their roster to avoid self-selection bias (Rosenthal & Rosnow, 1975; Rosenthal & Rosnow, 2008). The Captains (CPTs), including one female, were $M = 47$, $SD = 6$ years old and had $M = 13,380$, $SD = 3,626$ flight hours; the First Officers (FOs), including five females, were $M = 33$, $SD = 5$ years and had $M = 5,325$, $SD = 2,723$ flight hours (Gontar, Hoermann, Deischl, & Haslbeck, 2014; Gontar & Hoermann, 2014).

4.2.2. Predictor variables

The flight experience predictor is operationalized by the amount of active affiliation in the air service which is the amount of years of ATP license holding as a pilot. Since the career as a pilot starts as FO on the short-haul, followed by being FO on the long-haul, going back to the short-haul as CPT, and finally being CPT on the long-haul, the selected sample of pilots ensures a high variance of experience. As decision making is the outcome of both crewmembers' cooperation, we use the flight crew as one entity and calculate the crews' experience as the sum of both individuals' amount of active affiliation.

In terms of the ability to generate associations, the remote association test (RAT) has a long history (Mednick, 1962; Kahnemann & Klein, 2009). Using RAT, the participants are asked to search for a common association of three given words (Kahnemann & Klein, 2009). A triple of *rat*, *blue*, *cottage*, for example, can be linked with *cheese* (Mednick, 1962). In order to avoid undesired bias by language proficiency, we designed our own word-triples using the German language. The German version is indicated by an asterisk (RAT*). In the style of the original RAT, 15 word-triples are presented to the participants; for each of the correctly-solved associations, the participant achieves one score point; the predictor is calculated as the sum of both crewmembers' RAT scores. Experience, as well as the ability to generate associations, is expected to positively influence the usage of recognition-primed decision-making (RPD_{usage}).

4.2.3. Decision-making process

The operationalization of the pilots' decision-making process follows the approach of Klein (1993b), in which he assigned decisions to be recognition-primed when the participants/subjects did not compare any options. If they compared a single action alternative and evaluated it, their decision-making process was assigned as analytical. The same approach is used in this study. If the crew compares different options, their decision-making process is assigned as analytical, non-recognition-primed (nRPD) respectively. After the

mission, the pilots were asked to recapitulate the scenario as a cognitive walk-through. To encourage this process, the pilots were asked to use paper-based record cards, as is known from the *Critical Incident Technique* (Kanki & Hobbs, 2010; Ostrom & Wilhelmson, 2012). This helped the visualisation of the thinking process of the pilots and supported the discussion of the two crew members, see Figure 2.

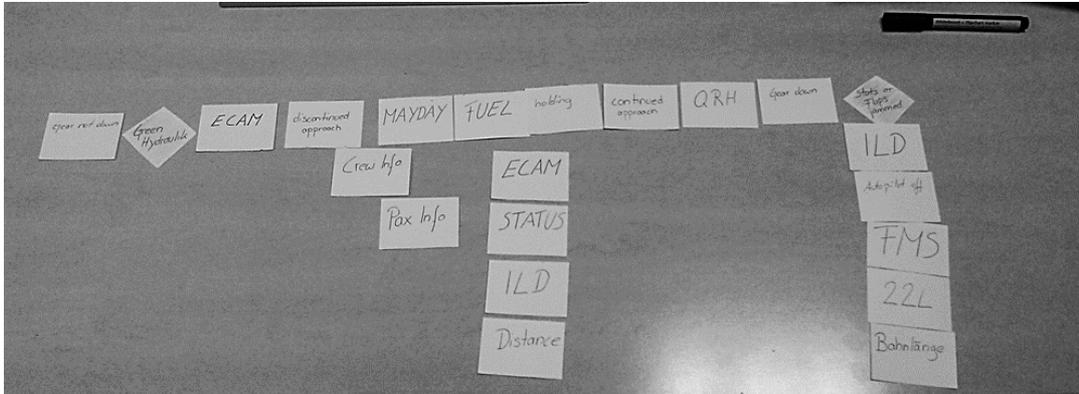


Figure 2. Paper-based record cards used by the pilots.

4.2.4. Dependent variables

To measure the variables depending on the kind of decision-making process, questionnaires were developed which asked for the different aspects. The benefit of experience for the specific scenario was asked on a five-point scale, ranging from *none* (=0) to *strongly* (=4): "Were you able to benefit from your experience during the just-flown scenario?" Subjectively-perceived uncertainties were collected with the question: "How often are you faced with uncertainties in the cockpit?" using a five-point scale ranging from *never* (=0) to *always* (=4). The instructor pilot rated the participating pilots' performance with the *LOSA Descent / Approach / Land* sheet on four different dimensions: *Planning*, *Execution*, *Review & Modify* and *Overall Behavioural Markers* (Klinec, Murray, Merritt, & Helmreich, 2003). The pilots were rated on a four-point scale from *poor* (=1) to *outstanding* (=4).

4.2.5. Experimental scenario

According to the mentioned context factors for naturalistic decision-making of Cannon-Bowers, Salas, and Pruitt (1996), a flight simulator scenario in a full-flight simulator (*JAR STD 1A Level D*) is appropriate. Therein, 120 pilots had to fly a challenging approach scenario either to New York (Airbus A340), or to Nice (Airbus A320). When they lowered their gear, the green hydraulic system indicated a leak, so that the nose-gear was not able to fully extend and lock, but also remained unable to retract. Due to the aerodynamic drag, the fuel consumption was doubled, with the result that the aircrews found themselves in a mayday situation with fuel on board for about 30 minutes remaining flight time. The crew then had to go around and work through the different procedures. With the hydraulic system being affected, the required landing distance of the aircraft increased, which again required the pilots to manually calculate the inflight landing distances. With this information provided, the pilots were now able to decide which runway they wanted to use in their second approach (*main decision*). During their following approach, the slats or the flaps also jammed due to the underlying green hydraulic problem, so that additional procedures had to be applied. As they are not important for this particular analysis, further details regarding the technical scenario can be found in Gontar and Hoermann (2014), or in Gontar and Hoermann (2015).

4.2.6. Experimental procedure

When the pilots entered the simulator, the aircraft was in freeze mode and in an appropriate configuration for the forthcoming approach. After the pilots had flown their mission, both pilots were separated into different rooms to rate themselves and their colleague regarding their CRM skills, such as communication, leadership, teamwork and work organisation, as well as their situation awareness and decision-making during their simulator mission. Both pilots were furthermore asked to fill out a questionnaire

regarding the benefits from their flight experience for this scenario and the uncertainties they are facing during flight operations. Those questionnaires were followed by a remote association task (RAT*) with 15 triple-word combinations with exactly two minutes to answer.

The debriefing began with a process-mapping, where both pilots mentally went through their simulator session whilst sorting record cards, which reflected their actions. During the process-mapping, the experimenter asked several questions to go into further details of the decision-making process. If one of the pilots stated that they had compared different options, the crew's decision was assigned to be non-recognition-primed; the participants were not told that this debriefing was conducted to analyse pilots' decision-making processes to avoid any unwanted effects, for example, of social desirability.

5. Results & Discussion

When speaking in terms of statistical significance, a .05 level is specified for these analyses; error bars refer to the standard deviations. The Kolmogorow-Smirnow (K-S) test statistics were calculated to analyse the assumption of normally-distributed data; as all the data sets are non-normal, the Mann-Whitney test was used when comparing mean values.

5.1. Descriptive Statistics for Predictor Variables

5.1.1. Experience and RAT*

The results of the descriptive analyses of the pilots' flight experience, measured with their active affiliation in the air service within the respective airline, reflect the different career stages and is shown in Figure 3. Testing on normal distribution, the K-S test revealed significant results, $D(119) = .09$, $p = .012$.

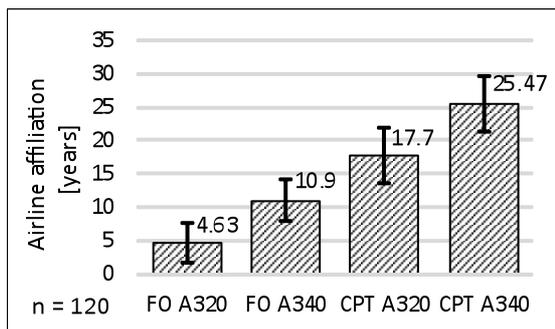


Figure 3. Pilots' experience as a function of crew position and fleet.

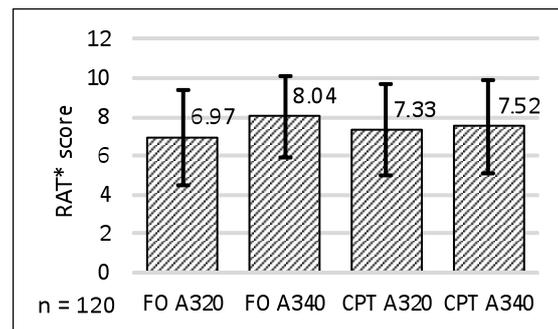


Figure 4. RAT* as a function of crew position and fleet.

The RAT*, reflecting the ability to generate associations, shows no differences between the four groups (compare Figure 4). There are no effects on the RAT* score – neither of crew position, nor of the fleet (short-haul or long-haul); the K-S test showed significant non-normally distributed results, $D(119) = .11$, $p = .002$.

5.2. Regression Model

Regarding the usage of the different decision-models, the analyses showed that only 34% of the pilots' *main decisions* can be attributed as recognition-primed (RPD group). The other 66% of the pilots were assigned to an underlying analytical decision-making process (nRPD group). We excluded the decisions of 12 pilots where we could not clearly assign their decision-making process; hence, comparisons of the RPD and nRPD group are based on $n = 108$ pilots. In comparison to other occupation groups (e.g. expert fireground commanders decisions: 58% recognition-primed), the proportion of RPD decisions seems to be relatively small (Klein 1993b).

A binary logistic regression, which does not require normally distributed data (Backhaus, 2006), to evaluate the predictors *experience* and *remote association* with regard to the probability of pilots' usage of recognition-primed decisions, was conducted. Thus, the test design introduced in Figure 1 can be modelled as the following: $RPD_{usage} = f(experience, remote\ association)$, where RPD_{usage} is the dichotomous dependent variable which reflects whether the crew's decision can be attributed to RPD or not.

Experience and *RAT** are defined as independent variables operationalized with the sum of the two pilots', (which form one crew) active affiliation in the air service within the respective airline, and with the sum of both pilots' ability to solve a remote association task. The results show that the overall model is not significant according to the chi-square statistic, $p = .66$; the same is true for the predictors, where experience leads to a *Wald* statistic of $.83$, $p = .36$, and the remote association to a *Wald* statistic of $.01$, $p = .92$.

These results lead to the conclusion that, in this setting, neither the experience of the pilots measured via their cumulative duration in air service, nor their personal ability to recognise patterns, influences the probability of recognition-primed decision-making.

5.3. Descriptive Statistics for Dependent Variables

5.3.1. Benefit of experience

The evaluation of the pilots' subjectively-perceived benefit from experience as a function of their crew position, is shown in Figure 5. Testing for normality, the K-S test showed significant non-normally distributed data, $D(116) = .30$, $p < .001$. There are no significant differences between the CPTs and FOs, $U = 1416$, $z = 1.61$, $p = .11$, nor between the short-haul and the long-haul pilots, $U = 1597$, $z = -.50$, $p = .63$.

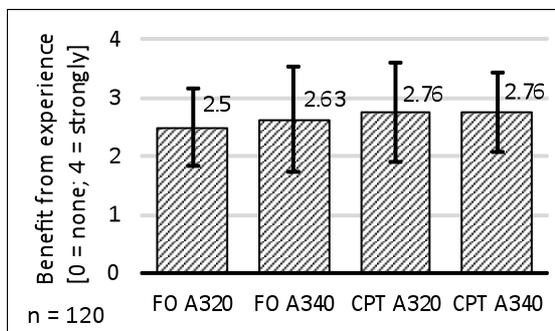


Figure 5. Benefit of experience as a function of crew position and fleet.

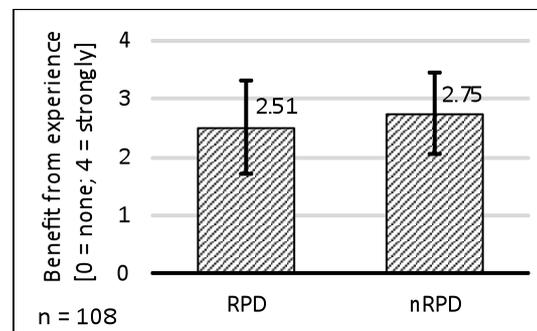


Figure 6. Benefit of experience as a function of the decision-making process.

The results regarding pilots' subjective benefit of experience show no significant differences between the RPD group and the nRPD group (cf. Figure 6), $U = 1131.5$, $z = -1.31$, $p = .19$.

5.3.2. Uncertainties

Regarding the uncertainties, none of the pilots stated that he/she is never faced with uncertainties. 33 pilots (28%) stated the amount of uncertainties as seldom; 58 pilots (50%) stated occasional; 23 Pilots (20%) stated often, and 2 pilots (2%) stated they are always faced with uncertainties. Figure 7 shows the subjectively-perceived amount of uncertainties during normal flight operations as a function of the crew position and fleet. The K-S test showed non-normal results, $D(116) = .26$, $p < .001$.

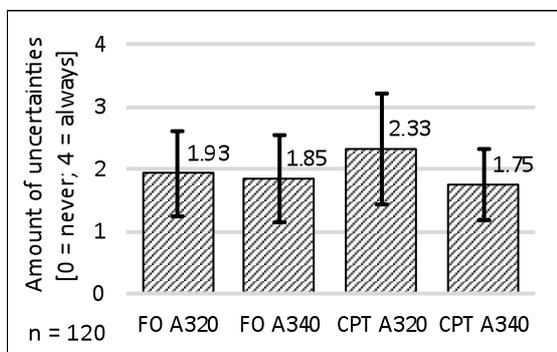


Figure 7. Perceived amount of uncertainties as a function of crew position and fleet.

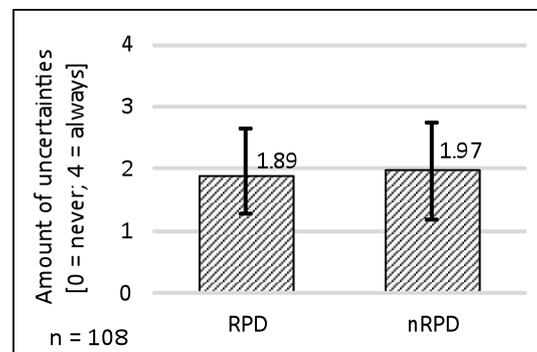


Figure 8. Perceived amount of uncertainties as a function of the decision-making process.

The non-parametric Mann-Whitney tests showed no differences between the crew position (CPTs and FOs), $U = 1581.5$, $z = -.60$, $p = .54$, but a strong trend between the fleet types (short-haul and long-haul), $U = 1368.5$, $z = -1.87$, $p = .06$ that short-haul pilots on the Airbus A320 perceive more uncertainties than A340 pilots. Grouping the pilots according to their decision-making process (compare Figure 8), no differences between the recognition-primed decision-makers (RPD) and the non-recognition-primed decision-makers (nRPD) have been found, $U = 1253$, $z = -.43$, $p = .68$.

5.3.3. Instructor estimation

The results of the instructor pilot's rating (cf. Figure 9) shows non-normal data distributions according to the conducted K-S test. The Mann-Whitney test shows significantly better ratings for the nRPD group, than for the RPD group, on the LOSA-dimensions of *Planning Behaviour*, $U = 1032$, $z = -2.32$, $p = .02$, and the *Review & Modify Behaviour*, $U = 952$, $z = -2.86$, $p = .004$. *Execution Behaviour* shows a strong trend, $U = 1102$, $z = -2.32$, $p = .06$. *Overall Behavioural Markers* do not show significant differences, meaning that the overall performance was not rated better or worse when pilots made recognition-primed decisions or not, $U = 1294$, $z = -.70$, $p = .49$.

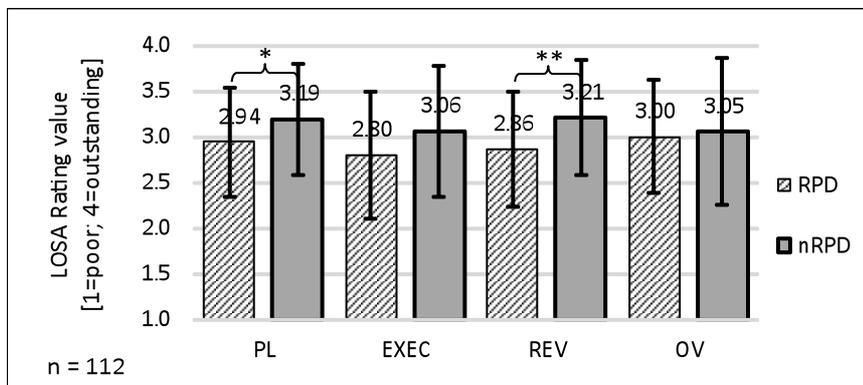


Figure 9. Instructor ratings as a function of different behavioural markers.

6. Discussion

Considering the results regarding pilots making less RPD decisions than other occupational groups (e.g. expert fireground commanders), this might have different reasons. As Klein (1993b) found, groups facing great pressure to justify, tend to use less RPD. This assumption might be applicable to pilots. All the decisions are stored on a data logger and, in the case of a malfunctioning system, a wrong or suboptimal decision causes different kinds of consequences; beginning with flight delays, which result in high costs, up to an accident with injuries or fatalities. Another explanation could be the fact that all the pilots in this sample had been intensively trained in the use of FOR-DEC, an analytical decision-making model, during their careers. Hence, in a decision situation, they might initially tend to look for options. The fact that the active affiliation in the air service shows no significant impact on the use of the recognition-primed model seems to be a contradiction. However, this contradiction is consistent with the independence of crew position on the perceived uncertainty of pilots. Pilots with more quantified flight time (CPTs), do not perceive fewer uncertainties or benefit more from their experience than flight beginners (FOs) do. This suggests that pilots are not always able to use their experience to cope with new and unknown situations, such as the scenario presented here. If the pilots are not able to build on transferable experience, the reasons for this have to be searched for in the pilots' environment. Aside from simulator training, challenging situations during normal flight operations are rare. Foreseeable simulator training missions, however, make it hard for pilots to build up experience in handling unforeseen events.

The results regarding the perceived benefit of experience show that it does not grow with the pilots' amount of flight hours or the simulator training sessions accomplished. This leads to the assumption that pilots, although learning something new during every flight and training, might not be able to transfer such knowledge to situations with a large amount of ambiguities. This might also be a result of the highly-automated working environment in combination with current training practice.

The trend that the A320 crews perceived uncertainties more often than A340 crews, might be attributed to the circumstances that short-haul crews (A320) perform more legs than the long-haul crews. As take-off and landing are also the most challenging flight phases, it seems logical that crews with more take-offs and landings face and perceive more uncertainties compared to long-haul crews who have to monitor the flight path for many hours in cruise flight. Another aspect could be that the A320 crew members are facing new tasks – the FO of the A320 only has little flight experience as he/she normally comes directly from flight school and does not have any airliner experience. According to the career steps (cf. Figure 3), the next step after being a (senior) First Officer on the long-haul fleet, is to go back to the short-haul fleet and to become a Captain. The CPT of the A320 is now responsible for the whole aircraft and the passengers. In contrast, the First Officer and the Captain of the A340 fleet have more experience in their respective tasks.

The significant difference between the RPD and nRPD groups in respect of the instructor pilot's *Planning Behaviour* rating might be due to the RPD users not comparing different options as the training standards would expect. Regarding the *Execution Behaviour*, it seems that both the RPD and the nRPD group perform on a comparable level with the trend to nRPDs being a little better. The same is true for the *Review & Modifying Behavioural Markers*, where again the nRPD group is rated to be better. According to Klein (1999), RPD makers completely mentally simulate their entire course of action at the beginning of their decision-making process. So, it seems consistent that the *Review & Modifying*, as well as *Planning Behavioural Markers*, are rated to be worse because these behaviours are not visible to the observer of RPD crews. A different explanation could be that, for the RPD group, it might be less important to review their already mentally simulated course of action again, as long as the perceived information does not change. As decision-making is only a part of the pilots' performance, the ratings for the *Overall Behavioural Markers* for performance do not show any significant differences.

In addition to the mentioned results, some limitations of this study will also be mentioned. The largest bias we see is the fact that we were not able to distinguish the decision-making processes between the two crew members, which resulted in only one common decision-making value [RPD, nRPD] for both pilots. Another aspect is the absence of a validated German translation of the RAT. We therefore had to translate and create word-triples for the provisional German RAT*.

7. Conclusion

As the occupational group of pilots is trained to use analytical decision-making processes, the presented results are in accordance with their standards. As every trained procedure has its limitations, training to cope with new and unforeseen situations seems to be a beneficial addition. Pilots are experts and therefore inherently able to build on experience. In case they decide against using their experience, as the pressure to justify is so high, the training philosophy could encourage them to do so; if pilots cannot use their experience, the training methods and pilots' environment should be adapted to allow pilots to build up their experience and handle uncertain and ambivalent situations. In both cases, whether they do not want to, or cannot use their experience, incorporating unforeseen events or malfunctions into current training practice would be helpful.

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