Economic issues provokes hazardous landing decision-making by enhancing the activity of "emotional" neural pathways

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***Abstract*— The analysis of aeronautical accidents highlights the fact that some airline pilots demonstrate a trend to land whereas the approach is not well stabilized. This behavior seems to be the consequence of various factors, including financial issues. Our hypothesis is that financial constraints modulate the brain circuitry of emotion and reward, in particular via the interactions between two prefrontal structures: the dorsolateral prefrontal cortex (DLPFC), main center of the executive functions (EFs), high level cognitive abilities, and the ventromedial prefrontal cortex (VMPFC), structure linked with the limbic system, major substratum of emotional processes. In our experiment, participants performed a simplified task of landing in which the level of uncertainty and the financial incentive was manipulated. A preliminary behavioral experiment (n = 12) was conducted. A second experiment using fMRI is in progress and a case study only is reported here. The behavioral data showed that the participants made more risky decision to land in the financial incentive condition in comparison to the neutral condition, where no financial incentive was delivered. This was particularly true when the uncertainty was high. The functional neuroimaging results showed that the reasoning performed in neutral condition resulted in enhanced activity in DLPFC. On the contrary, under the influence of the financial incentive, VMPFC activity was increased. These results showed the effectiveness of the financial incentive to bias decision-making toward a more risky and less rational behavior from a safety point of view. Functional neuroimaging data showed a shift from *cold* to *hot reasoning* in presence of the financial incentive, suggesting that pilot erroneous trend to land could be explained by a temporary perturbation of the decision-making process due to the negative emotional consequences associated with the go-around.**

Keywords: decision making, emotion, reward, piloting performance.

I. INTRODUCTION

Approach and landing are critical flight phases. They require formalised sequences of actions (*e.g.* to put and lock the gear down, to extend the flaps) and to follow an arrival procedure through several waypoints. They also require decision-making processes based upon rational elements like the maximum crosswind speed for a given aircraft. Uncertainty, a worsening factor since it generates psychological stress, can be high during landing. Moreover, several psychosocial factors lead some pilots to irrational decision-making, such as keeping landing on whereas all safety parameters are not respected [1]. According to the legislation, such hazardous conditions (*e.g.* thunderstorm, heavy rain, strong crosswind or windshear) require to go-around and to perform a new attempt to land more securely or a diversion to another airport. A study conducted by the MIT [2] demonstrates that in 2000 cases of approaches under thunderstorm conditions, two aircrews out of three keep on landing in spite of incompatible meteorological conditions. This phenomenon, called *plan continuation error* [3], also exists in general aviation. Indeed, the BEA (the French national institute for air accident analysis) revealed that this pilots' trend to land (the *get-home-itis syndrome*) have been responsible for more than 41.5 percent of casualties in light aircrafts [4].

II. ECONOMIC PRESSURES AND LANDING DECISION

Many experiments have addressed the difficulty for pilots to revise their flight plan and several cognitive and psychosocial explanatory hypotheses have been put forward [5] [6] [7] [8]. Another explanation to this trend to land in spite of bad meteorological conditions or an unstabilized approach may resides in the impact of a large range of aversive consequences associated with the decision to go-around. Indeed, a go-around generates a stress in the crew and the passengers, the pilot can feel it like a failure and it may lead to difficulties to reinsert the aircraft in the traffic. Moreover, a go-around has negative financial consequences for the company (fuel consumption in particular). An organisation's emphasis on productivity may unconsciously set up goal conflicts with safety. The culture of the company weighs on security: if it attaches a negative connotation to a go-around, it is an excellent candidate for landing accidents. One now-defunct airline used to pay passengers one dollar for each minute their flight was late until a crew attempted to land through a thunderstorm and crashed [9]. According to Orasanu [8], companies also emphasize fuel economy and getting passengers to their destinations rather diverting the flight, perhaps inadvertently sending mixed messages to their pilots concerning safety versus productivity. Those blurred messages create conflicting motives, which can affect unconsciously pilots' risk assessments and the course of action they choose. All these emotional pressures could alter the rational reasoning by shifting decision-making constraints from safety rules to economic optimization.

III. FROM COLD TO HOT DECISION MAKING

Neglected during the first half of the 20th century, the role of emotion on cognitive functioning has been recently fully established in the cognitive neurosciences. According to Koenig and Sander [10], this historical neglect of emotion is explained by the difficulty inherent to its investigation and by the influence of a scientifically-correct Cartesianism that considered the cognitive system as the "incarnation of reason". Today, it is commonly admitted that experiencing an emotion can trigger unconscious processes useful to decision-making, in particular when the uncertainty is high [11]. Many experiments put forward evidence of a strong interaction between the limbic system, "*emotional brain*", and other structures like the prefrontal cortex, the "*rational brain*". For instance, Drevet & Raichle [12] have shown the existence of a dynamic balance between regions of the limbic system (amygdala, posteromedial cortex, ventral anterior cingulate cortex) and regions more associated to EFs (dorsal anterior cingulate cortex, DLPFC). Similarly, Mayberg and colleagues [13] have put in evidence that an increased activity of limbic and paralimbic regions (subgenual cingulate, anterior insula) was proportional to the decrease in activity of neocortical regions (right prefrontal cortex, inferior parietal cortex) during the experience of sadness. These types of observations are supported by a study of Mitchell [14], which demonstrated that the activity of the DLPFC was inversely proportional to the VMPFC. A previous study of Goel and Dolan [15] have also highlighted this type of emotional and cognitive subdivision in the prefrontal cortex (PFC) in a reasoning task. In this study, when the reasoning task was performed without emotional induction, *cold reasoning*, DLPFC activations were found. When the same task was performed with emotional induction, *hot reasoning*, VMPFC activations were observed. All these studies allow to understand how emotion or stress are in relation to cognitive functions and how they can modulate the cognitive performance, in particular the EFs [16], mainly implemented within the PFC.

Our hypothesis is that *plan continuation error* may be, at least in part, related to a shift from *cold reasoning* to *hot reasoning*, in result of the different negative emotional consequences associated with the decision to go-around. C*old reasoning* may be supported by EFs whereas *hot reasoning* may be less rational from a safety point of view and more oriented toward company's financial interest. In a fully neuroergonomics approach, we propose to investigate this hypothesis by reproducing a simplified landing task performed in an fMRI.

IV. METHODS

A. Subjects

Two separate experiments were conducted. 12 physically and psychiatrically healthy volunteers were recruited from the local population to participate to the behavioral experiment (age: mean = 28, *SD* = 3.69). 1 participant (age 28) was scanned in the fMRI. All subjects were right handed as measured by the Edinburgh handedness inventory [17]. The experiment was approved by the local ethic committee and an informed consent was obtained before participation.

B. From aicraft to fMRI

The task was based on a simplified reproduction of a real flight instrument, the ILS (Instrument Landing System). The participants were instructed that they were flying a plane during the landing phase and that like pilots, they were allowed to avoid landing if they believed that landing was unsafe (Figure 1). Decisions were based on two elements of the ILS: the localizer and the glide path, which provide lateral and vertical guidance to adjust the trajectory of the aircraft to the runway. This information was given by two rhombuses, like in real life, displayed below and on the right of the PFD (Primary flight Display). It was explained to participants that the landing was safe when both rhombuses were close to the center of their axes, the farthest from the center the rhombuses were, the higher was the risk of crash. For each trial, the participants indicated their responses by pressing a button on the response pad. A first independent variable with two modalities was the degree of uncertainty, high or low, linked with the rhombuses position. The second independent variable was the type of incentive, neutral or financial. During the neutral condition, the incentive was only based on a feedback that gave information on the accuracy of the responses. During the financial condition, a financial incentive was added to the one that gave feedback on the accuracy of the responses. The task consisted of a set of 4 runs, 2 neutral, and 2 financial in which the level of uncertainty was manipulated according to the two modalities (high and low).

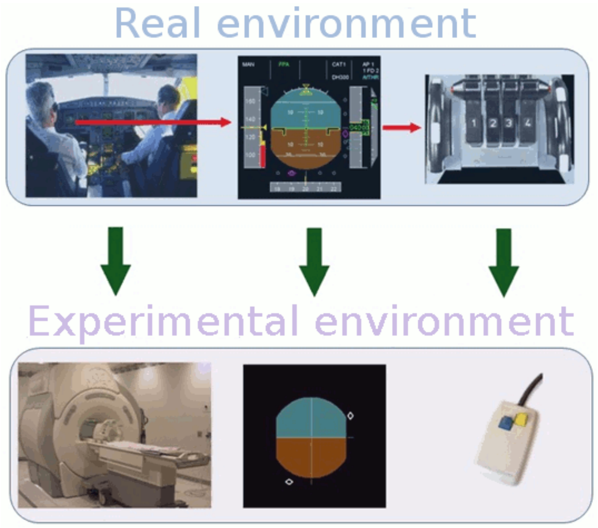

Figure 1. Simplified reproduction of the decision-making performed during the landing phase. In the upper part, the real environment. From left to right: the PFD within the cockpit, a zoom on the PFD and the throttle. In the bottom part, the experimental environment. From left to right: the fMRI, the simplified PFD (with only the two rhombuses of the ILS) and the response pad that allowed to decide to accept to land or to go-around.

C. *Stimuli*

1) *The ILS*

The stimuli was based on a 480x480 pixels simplified PFD with ILS and they reproduced a landing situation without external visibility. During the scan, they are displayed via back projection and an angled mirror in the head coil housing. Two different levels of uncertainty, depending of the positions of the two rhombuses, are randomly sorted within the 4 runs. In landings with low uncertainty, the decision-making was straightforward: either the rhombuses were very far from their respective center, requiring a go-around (likelihood of successful landing: 0%), either they were very close, requiring a landing acceptance (likelihood of successful landing: 100%). In landings with high uncertainty, rhombuses were borderline (not very far, not very close from the center) and the likelihoods (unknown by the subjects) of a successful landing or a crash is 50%. The positions of the two rhombuses were related to a score. Each axis was graduated with a 16 points scale, the most the rhombuses were far from the center, the higher was the score and the weaker was the likelihood to land securely (Figure 2).

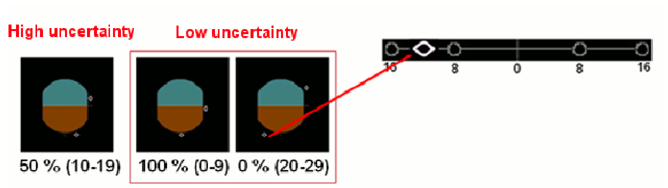

Figure 2. Categorization of the level of uncertainty according to the rhombuses positions. A score was computed according to the position of both rhombuses (the zoom gives information on only one rhombuse, the graduation was not displayed during the experimentation). The rhombuses position were counterbalanced to avoid laterality effects. The order of presentation of the stimuli was randomized.

2) *Feedback*

After each response, the participants received a feedback that informed on the response accuracy (OK, for a successful landing or a justified go-around; NO, for an erroneous decision to land or an unjustified go-around). During the condition with financial incentive, a second feedback gave information about the financial consequences of the decision (Figure 3). At the end of each run, a global feedback indicated the percentage of correct responses (*safety score*). Concerning the run with financial incentive, another feedback indicated the cumulative amount of money won or loss (*financial score*).

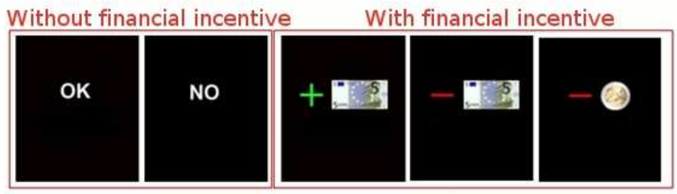

Figure 3. The various feedbacks displayed after each decision making. Without incentive, only the accuracy feedback was delivered (ok/no), with financial incentive, the monetary consequences are also displayed after the accuracy feedback.

D. *The payoff matrix*

During the financial incentive condition, negative emotional consequences associated with a go-around have been reproduced by a payoff matrix. This matrix was set up to bias responses in favor of landing acceptance. A go-around was systematically punished by a financial penalty. The penalty was less important (-2€) when the go-around was justified (in the case where rhombuses were very far from their center) than when it was unjustified (-5€). This systematic punishment of the decision to go-around reproduced the systematic negative consequences associated with this latter in real life. A successful landing was rewarded (+5€) whereas an erroneous decision to land was punished (+5€). The fact that the erroneous decision to go-around was less punished that the erroneous decision to land may appears counterintuitive but the matrix was set up in this way for two reasons. Firstly, in real life, the pilots know that crash and overrun are rather unlikely events whereas the negative consequences associated with a go-around are systematic. The analysis of unstabilized approach confirms that accidents are rather rare in spite of frequent risk taking [2]. Secondly, we could not reproduce the low frequency of accidents in an fMRI experiment because the cerebral signal associated with rare events could not emerge from a statistical point of view. For this reason, we were compelled to modulate the weight of the punishment rather than the frequency (Figure 4).

Case / Choice	GO	GO-A
GO	+5€	-2€
GO-A	-5€	-2€

Figure 4. Payoff matrix biased in favor of landing acceptance. A successful landing pays 5€, an erroneous decision to land costs 2€, a justified go-around costs 2€ and an unjustified one costs 5€.

E. *Experimental design for the behavioral study*

We used a 2x2 factorial design crossing the financial incentive (neutral and financial) and the uncertainty (high, 50% chance of crash, or low, 100% or 0% chance of crash). Stimulus display and data acquisition were done with Cogent 2000 v125 running under Matlab environment (Matlab 7.2.0.232, R2006a, The MathWorks, USA). Two types of runs were presented during the experiment: neutral and financial ones. There were three likelihoods (0%, 100%, 50%) of successfully landing (40 trials for 0%; 40 trials for 100% and 80 trials for 50%), depending on both positions of the rhombuses displayed on the PFD. These likelihoods were unknown by the subjects. Each trial consisted in a presentation of the stimulus (3 s) during which the participant performed his decision thanks to a response pad, followed after a delay (5.5 s) by the feedback informing of the accuracy of the response (2 s). During the incentive condition the financial outcome was also displayed ({+5€}, {-5€} or {–2€}. Finally, an inter trial interval (2 s) was introduced. Response and financial feedback delivery was contingent upon the subject's response

F. *Experimental design for the fMRI study*

The fMRI design was identical to that of the behavioral study excepted that the stimulus display duration was shorter (2.5 s) and that the delay duration (6-10 s) and the inter trial interval duration (3-9 s) were variables for neuroimaging technical issues. The long variable delay before the feedback allowed us to distinguish the hemodynamic signal associated with the decision taking during the stimulus presentation from the sustained signal associated with the reward uncertainty during the delay (Figure 5).

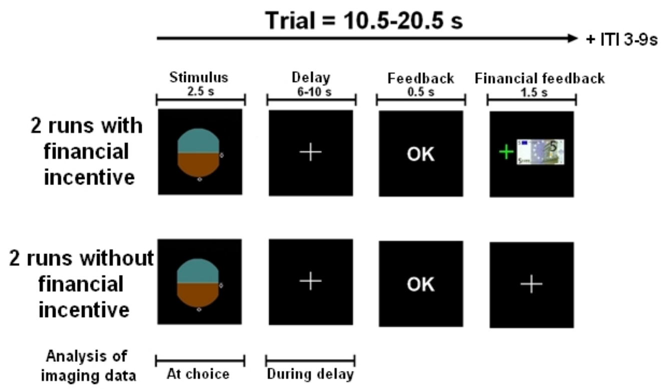

Figure 5. Experimental design. Four runs were performed by the participants (160 trials). The analysis of neuroimaging data was performed during the stimulus presentation (at choice) and during the delay. The order of presentation of the run was fully counterbalanced to avoid order effects.

Before the experiment, participants performed two runs (neutral and financial) to become familiar with the task and the payoff matrix. The training is identical to the behavioral task.

G. *fMRI image acquisition*

The experiment was conducted at the Fondazione Santa Lucia (Rome). All the data were acquired in a single session on a 3 T Allegra scanner (Siemens Medical Solutions, Erlangen, Germany) with a maximum gradient strength of 40 mT/m, using a standard quadrature birdcage head coil for both RF transmission and RF reception. The fMRI data were acquired using a gradient echo-EPI, with 38 axial slices with a voxel size of 3 × 3 × 3.75 mm3 (matrix size 64 × 64; FOV 192 × 192 mm2) in ascending order. The acquisition time was 2.47 s / 65 ms/ slice.

H. *Analysis of fMRI data*

Data analysis was performed within the Statistical Parametric Mapping analytic package (SPM5, Wellcome Department of Cognitive Neurology, London, UK). The data were sinc-interpolated in time. All images were re-aligned to the first acquired volume to correct head motion. Image was then spatially normalized and the transformation parameters were then applied to the functional volumes, smoothed with a (6*6*6*8 mm) isotropic Gaussian smoothing kernel. The preliminary analysis focused on non-specific effect of the financial incentive by collapsing reward regressor for the period of the stimulus and the delay and for every level of uncertainty. Thus two regressors were used: [low / high uncertainty, neutral], [low / high uncertainty, financial]

V. RESULTS

A. *Statistical analysis*

All behavioral data were analyzed with Statistica 7.1 (© StatSoft). The Kolmogorov-Smirnov goodness-of-fit test shown that data distribution was not normal, therefore, the effects of the financial incentive (neutral *vs.* financial), of the level of uncertainty (low *vs.* high) and their interactions on our dependant variables, the reaction times (RT) and the percentage of landing, were examined thanks to Friedman's ANOVA for overall effects and Sign test for paired analyses. The same type of analysis was also used to examine the effects of the type of stimulus (0%, 100% and 50%) on the same dependant variables.

B. *Behavioral results*

1) *Effect of Uncertainty on reaction times*

The Sign test revealed an effect of uncertainty on RT ($p < .023$). Higher uncertainty generated longer mean RT than low uncertainty (see Figure 6).

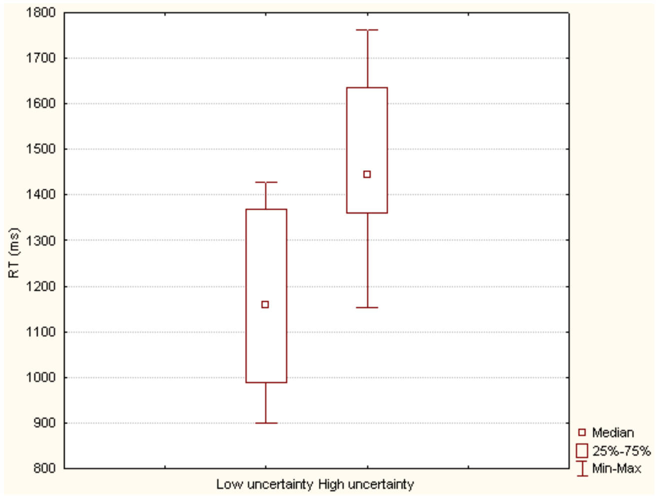

Figure 6. Reaction times (in ms) according to the two level of uncertainty (low and high).

2) Cross-effect of incentive and uncertainty on reaction times

The Friedman's ANOVA did not revealed an overall effect of the type of incentive on the RT. However, the Sign test revealed an effect of the financial incentive on RT ($p < .023$) for the stimuli where the landing was obviously possible (100% *vs.* 100%*). During the financial condition, the subjects RT were shorter than during the neutral condition, see Figure 7.

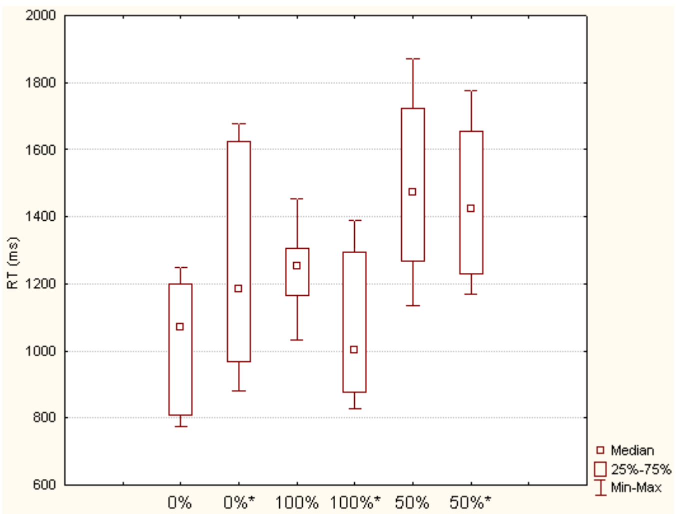

Figure 7. Reaction times (in ms) according to the 3 type of stimulus and for the two types of incentive. The asterisk indicates the presence of the financial incentive.

3) Cross-effect of incentive and uncertainty on decision making

In response to the asymmetric payoff matrix, subjects exhibited a significant shift in the likelihood of accepting landings. More precisely, the Sign test showed that under uncertainty (50% *vs.* 50%*), the percentage of landing acceptance increased ($p = .026$), from 32.093% ($SD = 12.06$) to 74.03% ($SD = 27.85$), see Figure 8.

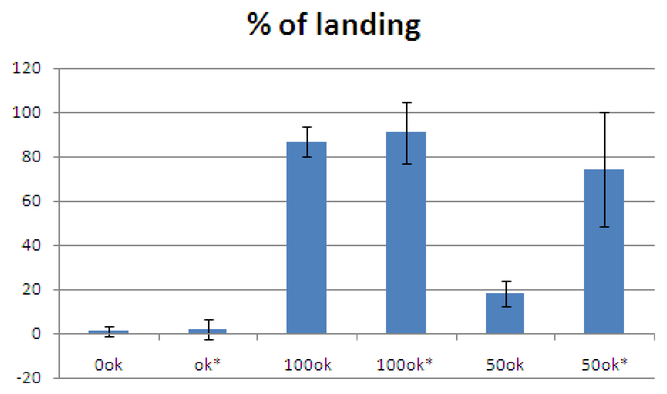

Figure 8. Percentage of landing acceptance according to the level of uncertainty and the type of financial incentive. Concerning the high uncertainty (50%), results showed a conservative behavior without incentive (under 50% of acceptance) and a risky behavior with incentive (beyond 50% of acceptance). The asterisk indicates the presence of the financial incentive.

C. *Functional neuroimaging case study*

The behavioral results of the subject that performed the task in the scanner were coherent with the behavioral group. The RT decreased in the financial incentive condition. Moreover the financial incentive generated a shift in the likelihood of accepting landings under high uncertainty, from 50% in the neutral condition to 85% of landing acceptance in the financial condition.

We investigated which brain regions were differently involved in decision-making under monetary incentive and in the neutral condition by performing overall contrasts that collapsed the time of choice and the time of the delay. The *cold reasoning*, performed during the neutral condition was associated with an increased activity in right DLPFC. On the contrary, the *hot reasoning*, performed under financial incentive was related with an increased activity in bilateral VMPFC (Figure 9).

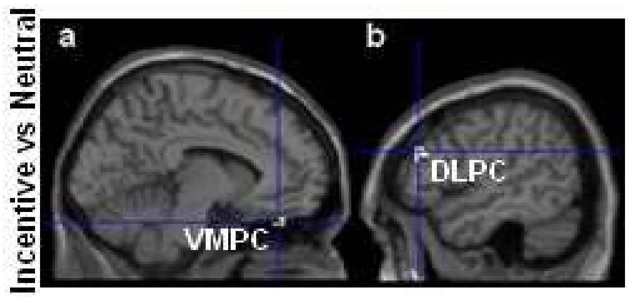

Figure 9. (A) Increased activation of the bilateral VMPC (BA11) during stimulus and delay for monetary incentive *vs.* neutral. (B) Increased activation of the right DLFPC (BA46) during stimulus and delay for neutral *vs.* monetary incentive ($p<0.01$; cluster > 15).

TABLE I. TALAIRACH COORDONINATES, Z-VALUE AND CLUSTER SIZES (K) OF THE ACTIVATED ANATOMICAL STRUCTURES FOR THE CONTRASTS NEUTRAL *VS.* FINANCIAL AND FINANCIAL *VS.* NEUTRAL. ALL AREAS WERE SIGNIFICANT AT $p < .01$ UNCORRECTED.

Anatomical structures (Broadman's area)	**Neutral - financial**					**Financial - neutral**				
	Talairach coordinates					*Talairach coordinates*				
	x	**y**	**z**	**z-value**	**k**	**x**	**y**	**z**	**z-value**	**k**
Frontal										
DLPFC (BA46)	53	36	19	2.35	22					
VMPFC (BA11)						-12	42	-24	2.33	21

VI. CONCLUSION

We used an approach borrowed from neuroeconomics to investigate the impact of an economic pressure, namely the cost of a go-around, on landing decision-making. This preliminary work reports behavioral results and a case study in fMRI. The behavioral data confirmed the impact of the financial incentive. Firstly, subjects responded with a slightly faster response time for the financial incentive condition when the decision to land was obvious (100%), showing more precipitate responses. The decision to land in this context is rewarded by 5€ and this reduction of the RT may be interpreted as a search of the reward at the expense of a detailed analysis of the rhombuses positions. Secondly, the financial incentive has biased responses toward more risky decision-making. Whereas, under uncertainty, participants are rather conservative during the neutral condition (32.093% of landing), they took more risky decisions under the influence of the biased payoff matrix. The payoff matrix has associated the go-around with immediate negative consequences and participants became reluctant to do it.

The preliminary neuroimaging results confirmed that the change in decision-making entailed by the financial incentive was subserved by a shift from a cerebral region dedicated to reasoning (DLPFC) to a region involved in emotion processing (VMPFC). The behavioral data associated to these neuroimaging results are in favor of a shift from a *cold reasoning* under the neutral condition to a *hot reasoning* in presence of the financial incentive. According to us, this shift can be generalized to pilots and demonstrates that the erroneous trend to land whereas the approach is not stabilized is the result, at least for a part, of the different aversive negative consequences associated with the go-around decision, in particular the financial cost for the company. This is suggesting that this phenomenon may be explained by a temporary perturbation of decision-making process under an emotional factor. Data from fMRI sessions are currently analyzed and include a total of 16 participants.

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