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Executive functions and pilot characteristics predict flight simulator performance in general aviation pilots

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In general aviation, 85% of the crashes seem to be caused by pilots' errors (Li, Baker, Grabowski, & Rebok, 2001) and 46% of the crashes occur at airports (Li & Baker, 1999). It is important to determine if the same factors influence the flying performance and the landing decision-making and to uncover which factors, among the pilot's cognitive status, personality traits and experience, are the most predictive. We examined in 24 general aviation pilots the relationship between those factors and the flying performance and weather-related decision-making relevance. The cognitive assessment encompassed the three basic executive functions (Miyake et al., 2000), reasoning and psychomotor velocity. The personal characteristics were age, flight experience and level of impulsivity. Reasoning, updating in working memory and flight experience were predictive of the flight performance. In

addition, updating in working memory, flight experience and level of impulsivity were linked with weather-related decision-making relevance.

Keywords: piloting performance, decision making, executive functions, impulsivity.

I. Introduction

Unlike commercial aviation (CA) aircrews, general aviation (GA) pilots have not necessarily experienced a professional training, fly mostly on their own, without a co-pilot or any assistance system (like the TCAS[1] or a sophisticated autopilot), have less support from the air traffic control and are more affected by weather conditions. Not surprisingly, in 2009, the National Transportation Safety Board (NTSB) revealed that the accident rate for GA, 1.33 fatal crashes per 100 000 flight hours, was 133 times the rate for CA (NTSB, 2009). Li and coworkers (2001) analyzed NTSB data files and showed that pilot error was a probable crash cause in 38% of the airline crashes and of 85% in the GA. Determining which factors, among the pilot's cognitive status, personality traits and experience, are predictive of his errors is a great challenge to improve safety in GA.

Flying is a complex activity that takes place in a rapidly changing and uncertain environment. The pilot must not only know how to operate the aircraft, the procedures and rules for flight, but also have an accurate and up-to-date situation awareness (SA) (Endsley, 1999). In a light aircraft, the basic

[1] Traffic Collision Avoidance System.

analogical and separated instrumentation requires mental effort and reasoning capabilities to maintain SA. A main source of difficulty is to comprehend accurately where the aircraft is and where it is going: since the light aircrafts' altitude is often relatively low, the loss of the aircraft's position awareness can provoke hazardous heading deviation (Gibson, Orasanu, Villeda, & Nygren, 1997). The greatest part of the GA fatalities occurs on route, away from the airports, but 46% of the crashes occur at airports (Li & Baker, 1999). Although it is little explored, the decision making performed during the landing phase is a very important issue. This phase requires following an arrival procedure through several waypoints and implies formalized sequences of actions (*e.g.* to adjust engine parameters, to extend the flaps…). It also requires decision-making processes based upon rational elements like the maximum crosswind speed for a given aircraft. In spite of the presence of such formalized rules and procedures, numerous pilots make erroneous decision. *Plan continuation errors* (Orasanu, Martin, & Davison, 1998) result when the pilot fails to perceive the changing context of the airspace and subsequently consider alternate flight plans. This phenomenon has been demonstrated both in commercial aviation (Rhoda & Pawlak, 1999) and GA: the BEA (the French Accident Investigation Bureau) revealed that these pilots' trend to land (called the *get-home-itis syndrome* in the study) has been responsible for more than 41.5 percent of casualties in light aircrafts (BEA, 2000). The failure to revise a plan is attributed to overconfidence (Goh & Wiegmann, 2001), lack of experience (Burian, Orasanu, & Hitt, 2000),

frequency of risk-taking behavior (Goh & Wiegmann, 2001) or loss of situation awareness (Orasanu, Martin, & Davison, 2001).

According to Hardy and Pasuraman (1997), the pilot flying performance is dependent on domain independent knowledge (*e.g.* cognitive functions), domain dependent knowledge (*e.g.* procedural knowledge), pilot stressors (*e.g.* adverse weather condition) and pilot characteristics (*e.g.* age, expertise…). Numerous studies have been conducted to link the cognitive functioning with the flight performance. Different measurements of cognitive efficiency have been identified as crucial to the piloting ability, for instance: time-sharing (Tsang & Shaner, 1998), speed of processing (Taylor et al., 1994), attention (Knapp & Johnson, 1996) or problem solving (Wiggins & O'Hare, 1995). Cogscreen-AE (Horst & Kay, 1991), one of the most widely used cognitive tests battery has been utilized to show that cognitive abilities were predictive of flight parameter violation in Russian CA pilots (Yakimovitch, Strongin, Go'orushenko, Schroeder, & Kay, 1994). Taylor and colleagues (2000) were able to predict 45% of the variance of the flight simulator performance with four Cogscreen-AE predictors (speed/working memory, visual associative memory, motor coordination and tracking) in a cohort of 100 aviators (aged 50-69 years). However, the identification of the most relevant cognitive functions to predict flight performance remains a key issue. A possible and original approach is to examine executive functions (EFs) since they underlie goal-directed behavior and adaptation to novel and complex situations (Royall et al.,

2002). They allow the inhibition of automatic responses in favor of controlled and regulated behavior, in particular when automatic responses are no longer adequate to the new environmental contingences. They also encompass decision making (Sanfey, Hastie, Colvin, & Grafman, 2003) or reasoning abilities (Decker, Hill, & Dean, 2007). According to Miyake (2000), three major low-level EFs are moderately correlated with one another, but clearly separable: set-shifting between tasks or mental sets ("shifting"), inhibition of dominant or prepotent responses ("inhibition"), and updating and monitoring of working memory (WM) representations ("updating"). EFs should be crucial to the piloting performance. Indeed, piloting takes place in an evolving and uncertain context, where new information must be integrated and updated continuously. EFs appear critical for handling the flight, monitoring the engine parameters, planning the navigation, maintaining an up-to-date SA, correctly adapting to traffic and environmental changes and performing accurate decision making by inhibiting wrong behavioral responses. Since EFs modulate mental flexibility, inhibition of inappropriate responses or the capacity to maintain up-to-date SA, they are essential to a decision-making performance based on relevant information. The trend to land, in spite of adverse meteorological conditions or an unstabilized approach, may thus be explained, at least in part, by a perturbation of EFs. Pilot characteristics are also critical since they are suspected to modulate flight performance (Hardy & Parasuraman, 1997). According to Sicard (2003), the flight safety is dependent on the quality of

decision making, a process that is closely related to risk taking. Impulsive individuals are more likely to make risky decisions, choosing immediate rewards despite potential long-term negative consequences (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001), suggesting an heightened sensitivity to reward and/or a reduced sensitivity to negative outcomes (Ainslie, 1975). Impulsivity is a personality characteristic described as "acting without thinking" and has a negative impact on decision making. Martin (2009) showed that, during risky choice, high impulsive people did not present the electroencephalography negative potential related to error processing, contrary to low impulsive people, suggesting that low impulsive individual evaluated risky choice as a poor decision whereas high impulsive individuals were biased towards immediate reward and were less sensitive to the negative consequences associated with their choice. Keilp (2005) has shown that the Go-No Go task, verbal fluency, EFs measures and tasks requiring decision making against time were strongly correlated to self-rated impulsiveness. On this basis, in aeronautics, trait impulsiveness is a psychological characteristic that may be predictive of risky decision-making, in particular during approach and landing phases, where the time pressure is important. A high level of impulsiveness could contribute to the *plan continuation error*. Among the different pilot characteristics, age is another critical factor. For instance, Li et al. (2005) have found that the accident risk began to increase from 35 years old in a cohort of 335,672 GA pilots. Hardy et al. (2007) examined the effect of age on pilot

cognition in a 28-62 years old sample and showed that the cognitive performance began to decline very early, from 40. This fall of cognitive performance is strongly suspected to be partly responsible for the increased accident rate with age. These data raise the importance to monitor the pilot cognitive functioning as long as the decline of these abilities represents a much higher risk of accidents than sudden physical incapacitation (Schroeder, Harris, & Broach, 2000). In addition to age, flight experience is well known to improve flight performance and to protect against aging effects (Harkey, 1996; Li et al., 2005; Taylor, Kennedy, Noda, & Yesavage, 2007).

In this study, we propose to focus specifically on the three low level EFs (shifting, inhibition and updating) and to link, in the same population, their efficiency to the flight navigation performance and the ability to make relevant decision during the critical landing phase. Few studies have examined overall flight simulator performance regarding cognitive scores. They are often related to the ability to perform radio communication, examined decision making aspects (Morrow et al., 2003; Taylor, O'Hara, Mumenthaler, Rosen, & Yesavage, 2005) or employ very simplified situation (Wiggins & O'Hare, 1995). In addition to EFs, we assessed two other well-established general abilities: reasoning and the psychomotor speed. Reasoning is central to cognition and reflects fluid intelligence that supports processes relevant for many kinds of abilities (verbal, spatial, mathematical, problem solving etc.) and adaptation to novelty. It is a concept very close to

executive functioning (Decker et al., 2007; Roca et al., 2009). The speed of processing also represents a reliable measure of general intellectual performance because it modulates the cognitive efficiency (Salthouse, 1992). Moreover, because age, total flight experience and the level of impulsivity are suspected to modulate the flight performance, we have taken into account these aspects in the analyses.

II. METHODS

A. Participants

The participants were 24 private licensed pilots (mean age = 43.3 years, *SD* = 13.6) rated for visual flight conditions. The mean level of education of our sample was high (15.45 years, *SD* = 2.06) and the mean total experience was of 1676 hours of flight (Range 57-13000). The pilots that had no longer flown during the past two years were excluded because of the potential impact on flight simulator performance. All participants had a previous experience with a PC-based flight simulator. Inclusion criteria were male, right handed, as evaluated by the Edinburgh handedness inventory (Oldfield, 1971), native French speakers, under or postgraduate. Non-inclusion criteria were expertise in logics, airline pilots and sensorial deficits, neurological, psychiatric or emotional disorders and/or being under the influence of any substance capable of affecting the central nervous system. All subjects received complete information on the study's goal and experimental conditions and gave their informed consent.

B. Flight performance

1) Navigation

The flight scenario has been setup in collaboration with flight instructors to reach a satisfying level of difficulty and realism. To familiarize the participants with the PC-based flight simulator and minimize learning effects in order to obtain reliable flight simulator performances, each volunteer underwent a training session. Before the navigation, they received the instructions, a flight plan and various technical information related to the aircraft (*e.g.* aircraft's crosswind limit). Basically, the scenario was to take off, reach a waypoint with the help of the aircraft radio navigation system and, finally, land on a given airport. The pilots were instructed that they were in charge of all the decisions and that they could only receive an informative weather report before landing. In order to increase the subject’s workload, on route, the pilots had to perform a mental arithmetic calculation of the ground speed (thanks to the embedded chronometer). Moreover, a failure of the compass was scheduled. After this failure, the pilots had to navigate thanks to the magnetic compass, which presents the particularity to be difficult to use, as it is anti-directional. The flight scenario lasted approximately 45 min. The flight performance assessment was founded on the flight path deviations (FPD), expressed in terms of amount of angular deviation in the horizontal axis from the ideal flight path. This measure is widely used as an indicator of the primary flight performance (Hyland, 1993; Leirer, Yesavage, & Morrow, 1989; Yakimovitch et

al., 1994). The deviation was summed from take-off to the waypoint before the landing decision, in order to assess the same flight segment for all the pilots. Indeed some pilots quitted the flight before others (because of the no-landing decision).

2) Crosswind landing decision

After the waypoint and before reaching the runway threshold, the pilots must state if the meteorological conditions, as provided by the automatic information system of arrival airport, were compatible with a landing or necessitate a go-around and a diversion. In this purpose, the pilots had to assess the crosswind component using a commonly utilized formula[2]. This formula is part of the very basic knowledge of pilots and a rather important wind (*i.e.* 10-15 knots) systematically leads the pilot to consider it. The calculation result exceeded of 6 knots the aircraft's maximum crosswind limit, as specified in the documentation provided to the pilots at the time of the flight preparation. The measured dependent variable was binary: correct when the pilot decided to divert before the runway threshold, incorrect when the pilots continued the landing beyond the runway threshold.

C. Pilots characteristics

Age and total flight experience were collected to assess their effects on the flight performance. The level of impulsivity of the pilots was measured by the French version of

[2] Crosswind (in knots) = effective wind (in knots) * sin (angle between runway and wind direction). Moreover, pilots have mnemonic methods to simplify this calculation.

the Barratt Impulsiveness Scale (Bayle et al., 2000). This test includes 34 items that may be scored to three first-order factors: cognitive (quick decision, 11 items), motor (acting without thinking, 11 items) and non-planning impulsiveness (present orientation, 12 items).

D. Neuropsychological battery

1) Target hitting

This test provides a basic psychomotor reaction time (Loubinoux et al., 2005). The instruction was to click as fast as possible on each target. The performance was measured by a velocity index inspired by the Fitts' law (1954). The index is the average ratio of the base 10 logarithm of the distance in pixels between two targets, divided by the time in seconds to go from the first target to the second.

2) The 2-back test.

The 2-back test aims at assessing WM, in particular maintenance and updating abilities (Chen, Mitra, & Schlaghecken, 2008). Subjects viewed a continuous stream of stimuli and had to determine whether the current stimulus matched in a specific dimension (shape for our test) the stimulus 2-back in the sequence. The percentage of correct responses was collected.

3) Deductive reasoning

The logical reasoning test has been used in a previous study to assess executive functioning (Causse, Sénard, Démonet, & Pastor, 2010). The goal of the task is to solve syllogisms by

choosing, among three suggested solutions, the one that allows concluding logically. Syllogisms are based on a logical argument in which one proposition (the conclusion) is inferred from a rule and another proposition (the premise). We used four existing forms of syllogisms: *modus ponendo ponens*, *modus tollendo tollens*, *setting the consequent to true* and *denying the antecedent*. Each participant had to solve 24 randomly displayed syllogisms. The measurement was the percentage of correct responses.

4) The computerized Wisconsin Card Sorting test

The Wisconsin Card Sorting test (WCST) (Berg, 1948) gives information on the subject's abstract reasoning, discrimination learning and shifting abilities (Eling, Derckx, & Maes, 2008). The test version here is a computer implementation very similar to the clinical version of the WCST (Heaton, 1981). The participant had to sort cards according to three different unknown categories (color, shape, number); an audio feedback indicated whether the response was correct or not (*yes/no*). When the participant categorized successfully ten cards, the target category was automatically changed. The task ended when six categories were achieved (color, shape, number, color, shape, number) or when the deck of 128 cards was used. The total numbers of perseverative errors (at least two unsuccessful sorting on the same category) was derived from the individual cards' records.

5) Spatial stroop

Spatial Stroop tests generally assess the conflict between the meaning of a word naming a location (*e.g.* "left") and the location where the word is displayed. The ability to restrain a response according to the localization of the word gives information on inhibition efficiency. This conflict appears to be provoked by the simultaneous activation of both motor cortices (Desoto, Fabiani, Geary, & Gratton, 2001). Our test encompasses four control conditions. "Stroop neutral meaning" (SNM): a motor answer is given with the appropriate hand according to the word meaning; "Stroop neutral position" (SNP): the response is given according to the location of a string of XXXXX, displayed at the left or the right of the screen; "Stroop meaning incompatible/compatible" (SMI/SMC): the response is given according to the meaning of the word, compatible or incompatible with its location at the screen. In order to get the pure effects of inhibition, the interference score was calculated to control reading and localization effects by: SMI - (SNP*SNM) / (SNP+SNM).

III. RESULTS

A. Statistical analysis

All data were analyzed with Statistica 7.1 (© StatSoft). Multivariate regression was used to determine the influence of the independent variables on FPD. Since FPD is a general index of piloting performance, not directly linked to decision making, impulsivity was not considered. The ability of the

remaining 7 independent variables to predict the piloting performance was tested by an all-possible-subset regression, an alternative to stepwise regression. This type of regression searches for the best possible fit between a dependent variable and a set of potential explanatory variables. Contrary to classical stepwise approach, an all-possible-subset regression searches the entire space of potential models for the best subset of regressors. Thus, the regression results are not affected by the order in which the variables are introduced in the model. In our study, our primary concern was the predictability of the piloting performance by the personal characteristics and the cognitive performance. The sample size was therefore calculated in this perspective. It was set for a multiple correlation coefficient of .7, a type-I error of .05 and a power of .8, after Cohen's method (Cohen, 1988). Finally, the landing decision being a categorical variable, we performed a discriminant analysis to examine the independent variables that discriminated between the pilots that had erroneously landed and the pilot that went-around.

B. Relations among the variables

Table 1 shows basic statistics. Pearson correlations were computed among all considered independent variables and between the FPD and the independent variables. With the exception of the reasoning performances, all the neuropsychological variables were significantly correlated with the age. Bravais-Pearson correlation shown that the three low level executive functions performances – updating in WM ($p < .001$, $r = -.73$),

inhibition (p = .011, r = .57) and set-shifting (p = .034, r = .48) — decreased with age. The speed of processing was also significantly reduced with age (p < .001, r = -.71). That was not the case of the reasoning performance that solely showed a trend to decline (p = .066). These analyses also revealed that there was no relationship between age and total flight experience.

TABLE 1
Means, standard deviations, and measures of association among the variables (* $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$).

Variables	***M***	***SD***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***
1. Flight path deviation	27.96	10.38	–	.27	-.11	-.16	-.00	-.01	-.39	-.63**	-.35	.25	.15
2. Age	43.3	13.6	–	–	.39	-.29	-.05	-.29	-.71***	-.38.38	-.73***	.48*	.56**
3. Total flight experience	1676	2992	–	–	–	.10	.26	-.16	-.27	-.16	-.61**	.22	.37
4. Motor Impulsivity	10.9	5.95	–	–	–	–	.23	-.23	.39	-.00	.30	-.25	-.41
5. Cognitive Impulsivity	16.1	5.56	–	–	–	–	–	-.29	.08	-.13	-21	.41	.03
6. Non-planning Impulsivity	14.85	5.47	–	–	–	–	–	–	.09	.09	.31	-.36	.11
7. Speed of processing	.276	.038	–	–	–	–	–	–	–	.43*	.56**	-.26	-.50*
8. Reasoning	61.11	15.42	–	–	–	–	–	–	–	–	.34	-.40	-.07
9. Update in WM	76.64	14.95	–	–	–	–	–	–	–	–	–	-.45*	-.55*
10. Set-shifting	5.54	8.43	–	–	–	–	–	–	–	–	–	–	.15
11. Inhibition	344.92	49.23	–	–	–	–	–	–	–	–	–	–	–

C. Explanatory variables of the piloting performance

The mean FPD amplitude was 27.69 (*SD* = 10.38). All-possible-subset regression revealed that the performances of two cognitive abilities were predictive of the FPD (See Figure 1): reasoning and updating in WM (respectively, $p = .0083$, $F(1,15) = 9.20$, $p = .0395$, $F(1,15) = 5.08$). Moreover, the total flight experience was also a significant explanatory variable ($p = .0275$, $F(1,15) = 5.95$). The more efficient the reasoning (see Figure 2) and the updating abilities were, the smaller was the FPD. In the same way, the more the pilots were experienced, the smaller was the FPD. The multiple correlation coefficient was .078 (thus superior to .07), giving a good reliability to these results. All-possible-subset regression did not reveal any significant effect of age, speed of processing, set shifting and inhibition on the piloting performance.

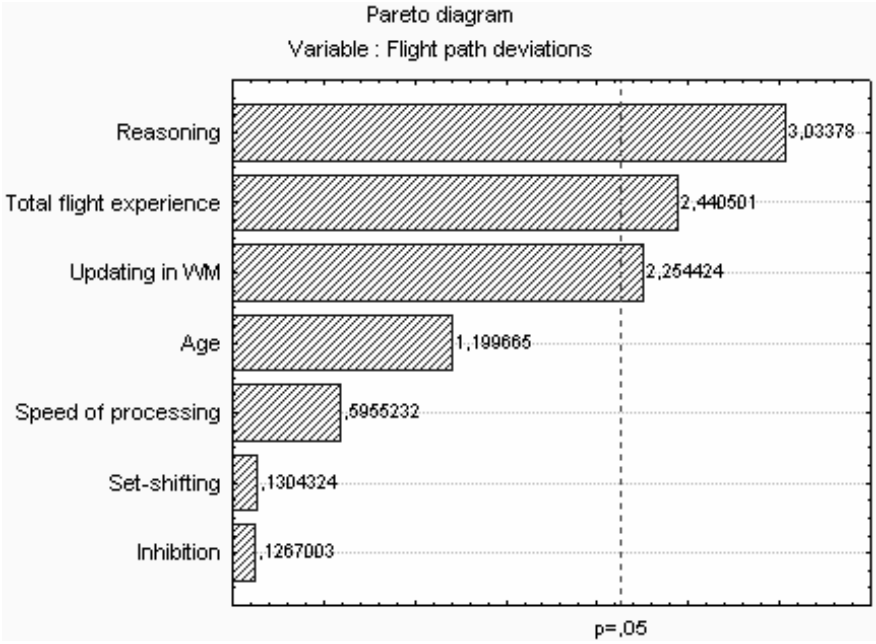

FIGURE 1 Synthesis of the all-possible-subset regression. The Pareto diagram shows the three predictive variables of the flight performance: the reasoning abilities, the updating in WM and the total flight experience.

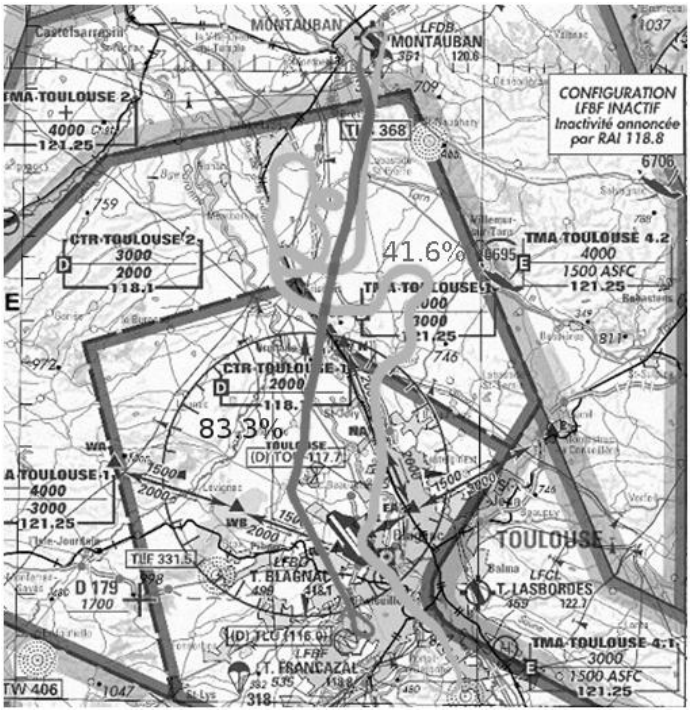

FIGURE 2 Flight path of two pilots and their respective reasoning performances. The dark line shows a pilot that had a small flight path deviation and a good reasoning performance (83.3% of correct answers). The light line illustrates a pilot that had a large flight path deviation, got lost and flew by mistake above the Blagnac airport. His reasoning performance was very low (41.6% of correct answers). The width of the line codes the altitude.

D. Discriminative variable of the crosswind landing decision

The data showed that 41.6% of the pilots erroneously kept on landing in spite of adverse wind conditions. The discriminant analysis revealed that three variables were predictive of the correct decision to go-around: updating, flight experience and level of motor impulsiveness, see Table 2. The pilots who made

the good decision to go-around demonstrated a better percentage of correct responses in the 2-back task, a larger total flight experience and a lower motor impulsiveness compared to pilots who made a poor decision (respectively $p < .001$, $F(1,14) = 20.676$; $p = .004$, $F(1,14) = 14.263$; $p = .030$, $F(1,14) = 6.528$). In addition, the non-planning impulsiveness was nearly significantly predictive of the decision-making relevance ($p = .059$). Neither the age nor the reasoning performance were predictive of the relevance of the decision making. The classification matrix showed that this model classified correctly 100% of the pilots who made a poor decision and 91.6% of the pilot who chose to go-around.

TABLE 2
Summary of the discriminant analysis by exhaustive search: neuropsychological indices of performances that predict crosswind landing decision (* $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$).

Variables	**β**	***Standard error***	***F(1,14)***	***t***	***p***
Age	.224	.172	.417	.646	.534
Total flight	.925	.113	14.263	3.776	.004**
Motor Impulsivity	-.627	.123	6.528	-2.555	.030*
Cognitive Impulsivity	.041	.102	.042	.205	.841
Non-planning	-.475	.110	4.630	-2.151	.059
Speed of processing	.268	.132	.928	.963	.360
Reasoning	-.144	.116	.486	-.697	.503
Update in WM	1.551	.162	20.676	4.547	.001***
Set-shifting	-.379	.112	2.584	-1.607	.142
Inhibition	.264	.130	1.072	1.035	.327

IV. Discussion

A. The piloting performance

The pilots were submitted to a neuropsychological battery that taped three crucial low-level executive functions (Miyake

et al., 2000) plus reasoning and speed of processing. Eventually, as revealed by all-possible-subset regression, reasoning performance was the variable the most predictive of the ability to pilot in our study. The reasoning performance reflects fluid intelligence, a central cognitive ability linked with various types of mental activity (calculation, problem solving *etc.*) and is essential to the adaptation to novel problems. Complex and novel problems cannot be solved directly by referring to a store of long-term knowledge but require analytic or fluid reasoning. To our knowledge, the relationship between reasoning and piloting performance in terms of heading deviation is an innovative result. The complexity of our flight scenario with an unexpected event like the compass failure appears to have contributed to a strong involvement of reasoning abilities. The pilots ought to perform numerous operations during the navigation to estimate their position and they had to use the radio navigation systems to reach a waypoint. In addition, the scheduled compass failure required pilots to use the anti-directional magnetic compass as a backup. The utilization of this instrument is counterintuitive and could have been a source of difficulty. Although we did not assess precisely the errors associated with the use of this instrument, it seems likely that it has participated to increase the path deviation of some pilots. Updating ability was also linked with the pilot’s performance. This result is not surprising. Indeed, the pilot’s activity takes place in a dynamical and changing context where new information must be integrated and updated continuously. The updating performances

appeared crucial in this context, most likely to maintain up-to-date SA. Previous work showed that losing SA may provoke hazardous heading deviation (Gibson et al., 1997). We did not retrieve a significant effect of the speed of processing nor the set shifting and inhibition. We may argue that the task that we used to assess the speed of processing had a strong motor component, probably not very relevant to our flight performance assessment, which was more dependent on higher-level cognitive abilities. Concerning set shifting and inhibition, we may consider that the characteristics of our flight scenario did not strongly involve these abilities. Contrary to updating, their efficiency seemed not crucial to reach a good level of performance. Finally, age was not a relevant variable to predict the piloting performance. According to us, this observation raises the limitation of using the chronological age as a single criterion to decide if a given pilot is able to fly or not. In accordance with such statement, Schroeder (2000) has pointed out the necessity to use neuropsychological tests rather than relying on age. Finally, the total flight experience was also predictive of the FPD. In accordance with other studies (Harkey, 1996; Li et al., 2005; Taylor et al., 2007), this data has confirmed the beneficial impact of experience on flight performance. For instance, Taylor (2007) showed in a 3-year longitudinal study that more expert pilots demonstrated better flight summary scores, and present less declines in flight simulator performance over time.

B. The landing decision relevance

In accordance with several authors (Dehais, Tessier, & Chaudron, 2003; Goh & Wiegmann, 2001; Goh & Wiegmann, 2001; Goh & Wiegmann, 2002; Muthard & Wickens, 2003; Orasanu et al., 2001), our results confirmed the difficulty of pilots to revise their flight plan, especially during the final approach where a great number of them keep on landing in spite of adverse meteorological conditions (Rhoda & Pawlak, 1999). In our experiment, updating, flight experience and motor impulsiveness were predictive of the landing decision relevance. Updating performance has probably modulated the ability to integrate the meteorology degradation during the flight scenario course. Moreover, the aircraft's maximum crosswind limit was not recollected in WM during the critical time of the approach. This is coherent with a survey of Ebbatson (2007) that showed that 30% of the participants could not recall or inaccurately recalled the crosswind limit of their aircraft. This inability to recollect critical information and to maintain an up-to-date SA seems to lead pilots to erroneously persist on landing. This is also consistent with Muthard’s (2003) study that highlighted the great difficulties encountered by some pilots to integrate critical contextual changes such as deteriorating weather. The reasoning performance was not a predictive variable. As a matter of fact, the pilots who erroneously land did not performed the crosswind calculation step. Given that the 2-Back task also assesses the maintenance in working memory, another possible explanation is that the participants did not keep in mind the whole radio-communicated message, in particular the

critical wind speed data. This is consistent with Morrow (Morrow et al., 2003) and Taylor (Taylor et al., 2005) results who showed that poor WM performances degraded the ability to follow ATC radio communication. The total flight experience was also predictive of the landing decision relevance. Indeed, the least experienced pilots were more likely to make erroneous decision. These results are consistent with those of Wiegman (2002) who has shown that the time and distance travelled into adverse weather prior to diverting were negatively correlated with pilots' flight experience. These findings and our results suggest that landing continuation may be attributable, at least in part, to poor situation assessment, consequence of a lack of experience. A relevant explanation is provided by Wiggins & O'Hare (1995). According to the authors, both information search and problem solving are less efficient in inexperienced pilots during weather-related decision making. Eventually, the level of motor impulsiveness, habitual propensity of a person to act without fully considering the consequences of his or her actions, was also a relevant predictor of the erroneous decision to land. To our knowledge, no study has linked the level of impulsiveness with the *plan continuation error*. According to Sicard (2003), a great level of impulsivity is deleterious to the relevance of decision making because of the increased risk-taking that it generates.

A main issue in GA is the loss of the aircraft’s position awareness that can provoke hazardous heading deviation (Gibson et al., 1997). In our study, the results have highlighted the

role of the reasoning, the updating in WM and the total flight experience in the ability to follow properly the lateral flight path. In addition, 41.6% of our pilots have erroneously kept on landing in spite of adverse wind conditions, confirming the great difficulty to revise the flight plan and divert to another airport. The updating in WM, the total flight experience and the level of impulsivity have proven to be predictive of the relevance of this weather related decision making. Linking cognitive function, flight experience and the level of impulsivity with hazardous aeronautic decision making provide new insight into the *plan continuation error*, particularly deadly both in CA (Rhoda & Pawlak, 1999) and GA, where it is accounting for over 41.5% of casualties (BEA, 2000). Even if our results must be replicated with more subjects in full-flight simulator, they encourage the definition of such batteries including neuropsychological tests and personality evaluation, administered to pilots during their medical examination. It would contribute to improve aviation safety, particularly when obvious cognitive decline or a strong level of impulsiveness is observed.

C. Application of the study

Results of this study confirm that neuropsychological tests and personality evaluation are reliable means to predict piloting and decision-making performances. This is an important issue as long as the cognitive decline is subtle and may impact flight safety. These types of experiments pave the way to the development of dedicated software (including neuropsychological

test and personality assessment) that could be administered for pilot certification. This could help prevent dangerous behaviors, in particular by detecting subtle, though crucial, cognitive impairments or an inadequate level of impulsiveness. In addition, a cognitive decline can reflect the onset of a neuropathology or be transient, and reflect the adverse effects of substance consumption (medication, alcohol…), or chronic stress, mental fatigue, depression… In such cases, its early detection could help pilots, by advising them and directing them to a medical staff.

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