UNIVERSITY OF MEDICINE AND PHARMACY OF CRAIOVA
FACULTY OF MEDICINE

SYNOPSIS OF DOCTORAL THESIS

THE STUDY OF CLINICAL AND PARACLINICAL PHENOMENA ENCOUNTERED DURING YAW STIMULATION OF SEMICIRCULAR CANALS

SCIENTIFIC COORDINATOR
PROF. IANCĂU MARIA, M.D., Ph.D.

Ph.D. CANDIDATE
MACOVEI ADRIAN

INTRODUCTION

Since the begging of human flight, the lack of visual stimuli triggered a feeling of danger and the lack of proper instruments made a flight in low visibility conditions (usually clouds) a significant vital risk. Among human sensorial systems, the most involved in flying was the vestibular one. Since 1990, Gillingham launched the spatial disorientation concept in academic media, underlining the integrative role of visual, vestibular and somatosensorial systems. (Gillingham, 1996).

I want to thank all those who have supported me in conceiving and writing this paper, especially to Professor Maria Iancău, M.D., Ph.D. and Professor Marian Macri, M.D., Ph.D. for their invaluable support both in experimental design and in clearing more difficult academic aspects and last, but not least, for their patience.

STATE OF THE ART

CHAPTER I displays the anatomical and functional characteristics of the vestibular organ. The five main sensors are reviewed: three semicircular canals, for the angular accelerations and two otholitic organs, for linear accelerations. Semicircular canals are situated orthogonally, so they cover all three axes. They form functional pairs, so each pair is situated in the same plan. (Smith, 2012). Hypocampic connections were not clearly identified, but the hypocamp is considered the integrator of spatial orientation. Recent studies (Smith 1997, Brandt 2005), based on electrophysiological methods, showed that vestibular stimulation involves anterior thalamic nuclei and the hypocamp. Several cortical areas were connected with vestibular integration. Guldin and Gurusser (1998) showed, on three different primate series, a vestibular cortical system. Neuroimagistic studies in humans confirmed some of the areas (De Waele, 2001; Lopez, 2011)

CHAPTER II resumes current data on spatial disorientation and motion sickness. Clinical manifestations in semicircular canals stimulation have two underlying mechanisms: variation of sensibility threshold and overstimulation of normal vestibular mechanisms. The chapter is structured in two parts, a review of vestibular illusions, like somatogyral illusion, leans illusion, Coriolis phenomenon, incapacitating nystagmus. Regarding motion sickness, it is a clinical phenomenon triggered by contradiction between sensorial inputs (vestibular system is the key factor, as labirinthectomized animals do not display motion sickness). Motion sickness appears to be an evolutionary response to a toxic component, leading to impaired vestibular function (Money, 1983). Several clinical entities were reported: sea sickness - 90% (Lawther, 1988), airplane sickness - 20-30%, bus sickness - 10% (Classen, 2011), roller coaster sickness, simulator sickness (Braitwhite, 1990; Kennedy, 1992), IMAX sickness (Flannagan, 2004), space sickness (Lackner, 2006).

CHAPTER III reviews evidences of vestibular autonomic regulation, focusing on multiple physiologic explorations like: skin pallor (Holmes, 2012), gastrography (Andre, 1996), endocrine changes (Kohl, 1978; Eversmann, 1985), RR variability (Doweck, 1997; Mullen, 1998). The second part is dedicated to considerations over vestibulo-autonomic integration: Wilson (2006) shows congruent vegetative modifications in vestibular stimulation in cats. Shortt (1997) shows sympathetical reactivity in head flexion, confirmed by Hume (1999). Ray (2002) attributes a role to vestibulo-sympathetic reflex in elderly orthostatic hypotension. Murakami (2002) shows vestibulo-autonomic regulation in mice. Kaufmann (2002) records vestibulo-autonomic regulation by polyphysiographic recordings. As a last argument, Cowings (1982) shows the efficiency of autonomic control techniques in controlling motion sickness.

PERSONAL RESEARCH

The second part displays the personal research.

In **CHAPTER IV** we aimed for the following **objectives:**

- study of leans perception as simulated by GAT II device

- Study of variation and discriminative threshold of yaw rotation (anterior experience made us think that this threshold is crucial to spatial disorientation training)
- study of under and over-threshold variations in performing a basic aviation task
- study of the impact of yaw rotation in controlling remote airplanes
- study of vestibulo-autonomic connections with impact on motion sickness

CHAPTER V describes the lots, the materials and the methods of the research.

The lots comprised entirely of volunteers, and were selected from pilots and paratroopers during their annual medical checkup. This offered us the opportunity to have well screened subjects, excluding any neurological, E.N.T. or metabolic disorder. During checkup, EKG, EEG and posturography were routinely performed. As reasonable achievable, we tried not to include the same subjects in every step of our research.

The first lot comprised of a number of 51 pilots and student-pilots, attending the GAT II training.

The second lot comprised of 60 subjects, 50 selected in similar conditions as the first lot, 10 selected of the GAT II „enthusiasts", taken the same screening procedure. According to their flight status, subjects were tagged as HEL (rotary wing), MIG (supersonics), TRA (transport), PAR (paratroopers), SUB (subsonic, 7 students and 3 instructors), ZER (non-pilots)

The third lot consisted of 20 subjects, 10 pilots and 10 non pilots, selected as above.

For the fourth lot we selected 10 pilot officers.

For heart rate variability study, we selected 20 pilots and 30 pilot candidates and first year pilots.

Materials used were, in principal, the GAT II simulator, capable of three axis rotation, according to the Table I parameters:

Table I GAT II parameters

Pitch +/- 12° Speed: 0 to 8°/s Acceleration: 0.5°/s² to 8°/s²	**Roll +/- 20°** Speed: 0 to 10°/s Acceleration: 0.5°/s² to 10°/s²	**Yaw (continuous) +/- 360°** Speed: 0 to 25 RPM Acceleration: 0.5°/s² to 15°/s²

For EKG date we used a portable EKG type BTL-08 SD1, selecting for printing the most prominent R wave channel.

R-R measuring was manual, with a special frequency ruler.

Variability data was processed with Kubios HRV 2.0 software

Methods of research are presented separately for each research phase:

1. Leans study

Performance evaluation was made with three items: FB for very good, B for good and S for satisfactory.

According to the perceived illusion, three categories were classified: DA – perceived illusion, NU – lack of illusion perception, but reacting in proper manner, CONFUZ – ones who couldn't accurately perceive a trend.

Pilot reaction was categorized as: ADECVATA – for the typical reaction expected, INADECVATA – for paradoxal reaction, INCERTA – the rest not pertaining to prior categories. Pilots for the last two categories of above classification were classified as INCERTA.

2. Yaw threshold

We used the GAT II simulator for generating a progressive 0.2 °/s² progressive acceleration, each stop larger than 5 seconds to minimize Mulder's law effect. Subjects were blindfolded and cockpit illumination reduced to a minimum.

3. Yaw rotation and deviation from course
The purpose was to find the effects of vestibular habituation and overstimulation over control capacities. For avoiding cross-coupling, the pilot vas immobilized with seat belt and cervical collar. Pilots had to take three runaway tours, once with no motion, one with below threshold rotation (acceleration de 0.4 ^{O}/s2 and speed 4 ^{O}/s) and one with high rotation (acceleration 2 ^{O}/s2 and speed 80 ^{O}/s). On flight recording we followed path deviation compared with static tour. We quantified the lateral deviation and the turn radius modifications. We defined a parameter name TAD (time to deviation), defined as time between rotation initiation and the deviation.
4. Yaw rotation influence over remote control.
Experimental part tried to show the influence of a motion base over UAV remote piloting. The issue was postulated by Cooke (2006). Subject selection was aimed towards good performance with the joystick. First stage was takeoff and path following, second (3 to 5 minutes) pitch rotation, 5 to 7 minutes roll rotation, 7 to 9 minutes simulated turbulences, and 9 to 11 minutes yaw rotation. Performance was quantified 1 to 3. Additionally, a supplemental modified motion sickness questionnaire was given. Pilots had to answer their perceived influence over control ability of the simulated motion.
5. Heart rate variability on yaw rotation and correlations with motion sickness
Profile had the following schedule:

- 0-30 s REST
- 30-60 s 4°/s o,4°/s2
- 60-90 s 40°/s 2°/s2
- 90-120s 85°/s 4°/s2
- 130s 20°/s 1°/s2
- 140s 5°/s o,5°/s2
- 150s STOP

EKG was recorded throughout profile. EKG data were converted to milliseconds with an Excel form and the input into Kubios HRV (the Suunto profile).
CHAPTER VI focuses on **results**, mentioning here the most important ones:
Tables II and III display correlations between illusion perception and flight experience, as well as execution ability.

Tabelul II Parametrul Perceperea iluziei față de Experiența de zbor și Capacitate de execuție (OZ =ore zbor)

Capacitate de execuție			Experiența de zbor					Total
			piloți subsonic	piloți supersonic peste 100 OZ	piloți supersonic sub 100 OZ	studenți fără OZ	studenți OZ subsonic	
B	Perceperea_ iluziei	CONFUZ	0	0	0	0	2	2
		DA	1	1	1	4	15	22
		NU	0	0	1	0	2	3
		Total	1	1	2	4	19	27
FB	Perceperea_ iluziei	DA	3	8	3		0	14
		NU	0	0	0		1	1
		Total	3	8	3		1	15
S	Perceperea_ iluziei	CONFUZ				1	0	1
		DA				4	1	5
		NU				3	0	3
		Total				8	1	9

Tabelul III Semnificația statistică a corelațiilor din tabelul II

Capacitate de execuție		Valoare	df	Semnificație
B	Pearson Chi-Square	4.748	8	.784
	Likelihood Ratio	4.730	8	.786
	Număr de cazuri	27		
FB	Pearson Chi-Square	15.000	3	.002
	Likelihood Ratio	7.348	3	.062
	Număr de cazuri	15		
S	Pearson Chi-Square	.900	2	.638
	Likelihood Ratio	1.275	2	.529
	Număr de cazuri	9		

Table II Illusion perception vs. flight experience ***Table III Statistical significance of table II***

There were no significant correlations between groups, showing that illusion perception does not depend on flight experience. We did find a significant correlation in high performance group, showing that from a certain level differences in perceived illusion are more due to training than to individual characteristics.
As a confirmation, tables IV and V show execution capacity correlation with illusion response.

Tabelul IV Parametrul Răspunsul la iluzie față de Capacitate de execuție

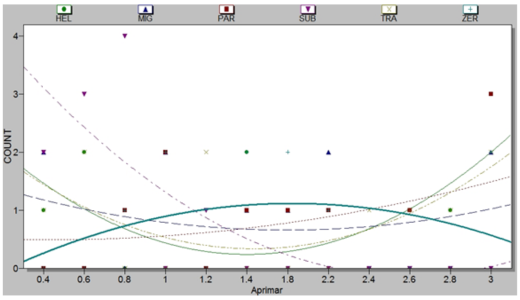
		Capacitate de execuție			Total
		B	FB	S	
Răspunsul la iluzie	ADECVAT	16	14	0	30
	INCERT	9	1	5	15
	INADECVAT	2	0	4	6
	Total	27	15	9	51

Tabelul V Semnificația statistică a corelațiilor din tabelul IV

	Valoare	df	Semnificație
Pearson Chi-Square	23.573	4	.001
Likelihood Ratio	27.589	4	.001
Număr de cazuri	51		

Tables IV and V Illusion response vs. execution ability and its statistical significance

Figures 1 and 2 display group distribution of *aprimar* and *areal*



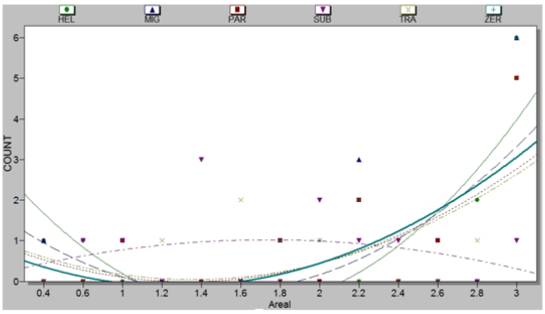
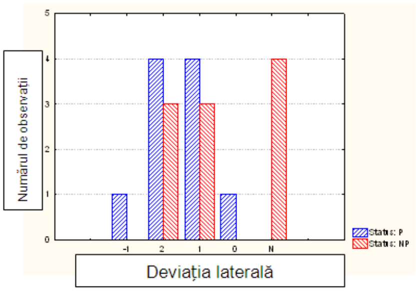


Figure 1 aprimar tendencies *Figure 2 areal tendencies*

ANOVA for aprimar shows a p value of 0.03, significant in our conditions. (Bartlett test of 0.32). Mann-Whitney for multiparametric testing shows a 0.02 p.

ANOVA for aprimar shows a p value of 0.05, significant in our conditions. (Bartlett test of 0.44). Mann-Whitney for multiparametric testing shows a 0.03 p.

In analyzing deviation, we note strong rightward skew of non pilots (figure 3), due to a neuromotor coordination below that of seasoned pilots. The symptoms (figure 4) were quantified 0-3. Pilots scored 0 (no symptoms) or 1



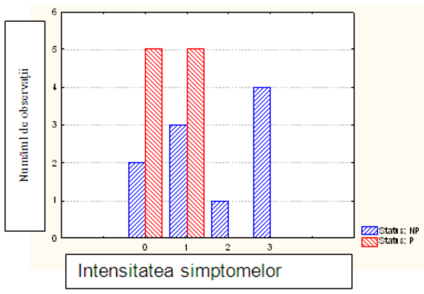
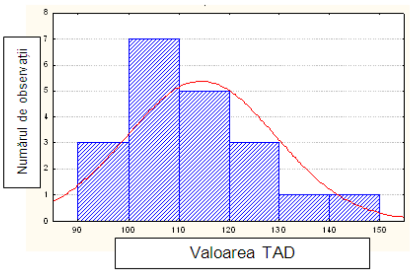


Figure 3 Lateral deviation histogram *Figure 4 Symptom scale*

TAD histogram is displayed in figure 5. TAD had a normal distribution and a standard deviation of 14.82. There is a significant difference between pilots and non pilots (p of 0.003), as shown in figure 6, pilots having superior control abilities, as well as a habit of referring to instruments.



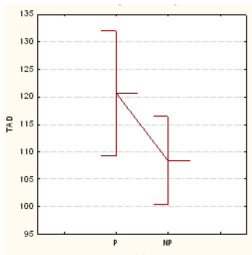
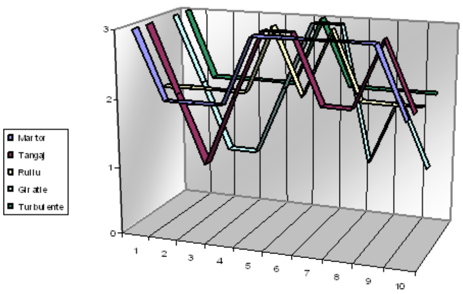


Figure 5 TAD histogram *Figure 6 TAD ANOVA*

Regarding remote control, the performance is displayed in figure 7. Chi Square Asymptomatic Significance (2-sided) between 0.549 and 1.000, do we have no differences in performance. Regarding symptoms (figure 8), 4 subjects had very small symptoms, and 2 small symptoms). 24 hours post experiment, none of the subjects had any problems.



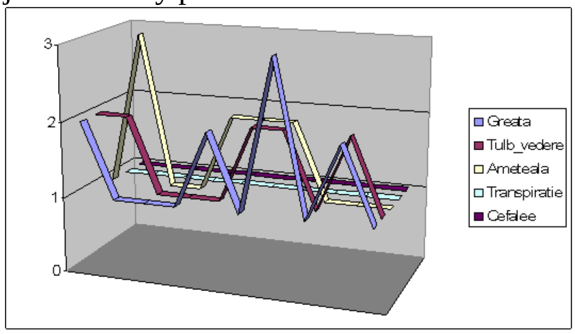
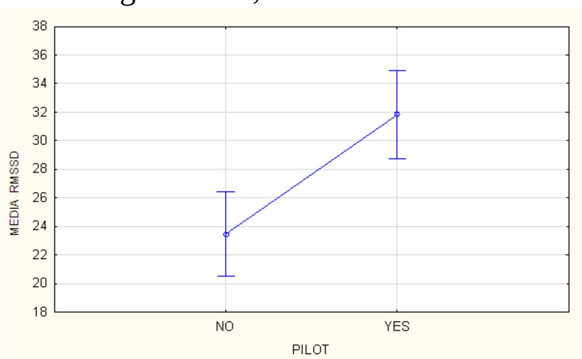


Figure 7 Performance display *Figure 8 Symptoms display*

Regarding heart rate variability RMSSD ANOVA shows an F factor of 15.241 with a minimal p of 0.0002 (figure 9), statistical significant between pilots and non pilots. Higher variability of the pilots is an indicator of lack of sympathetic activation. pNN50 ANOVA (figure 10) have similar significance, with F 15.359.



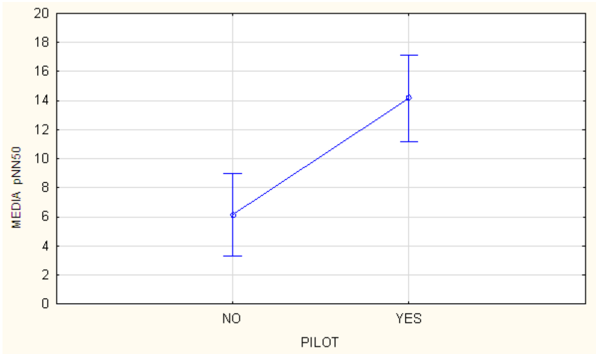
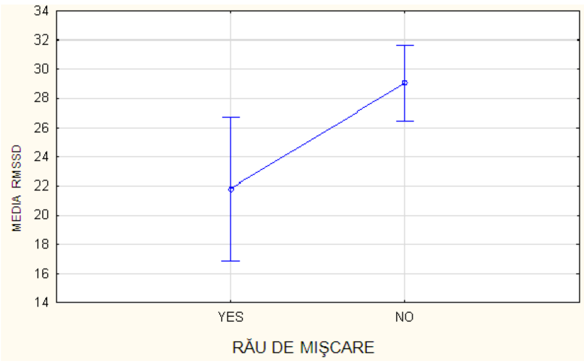


Figure 9 ANOVA RMSSD - Pilot *Figure 10 ANOVA pNN50 - Pilot*

Regarding motion sickness symptoms (MS) associated with mean RMSSD (figure 11), f value is smaller of 6.67 and p is 0.01. Values could be regarded as significant, but in our lot composition we chose not to validate it. Similarly for pNN50 (figure 12), more specific in our study, p is 0.013 and F even smaller 6.64.



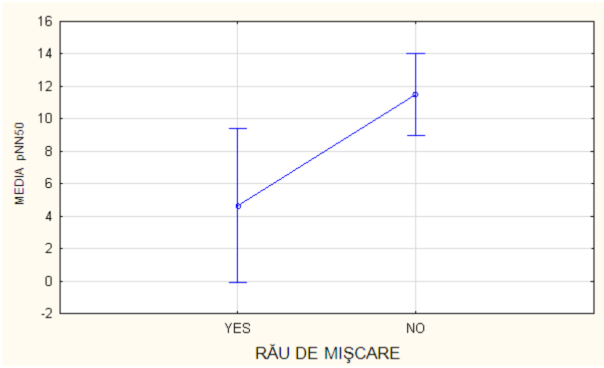
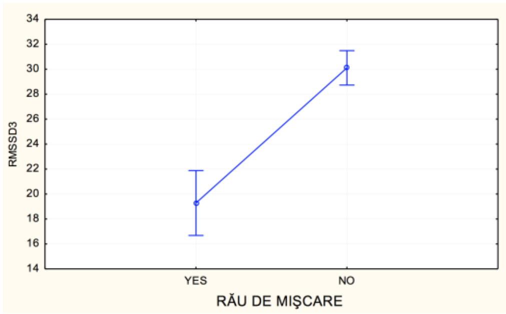


Figure 11 ANOVA RMSSD – motion sickness *Figure 12 ANOVA pNN50 – motion sickness*

At OT profile (coded 3 in graphic), correlation mean RMSSD – motion sickness has and F value of 54.78 with a p 0.001, highly significant. In this profile, it can be said that there is clear association between motion sickness symptoms and low variability. In pNN50 (figure 14) F value is 68.81 and p is 0.001, showing an even stronger correlation.



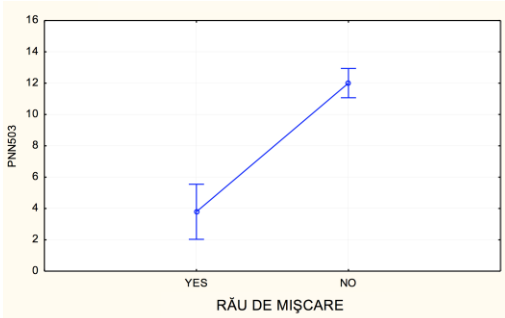


Figure 13 ANOVA RMSSD03 – motion sickness *Figure 14 ANOVA pNN5003 – motion sickness*

Chapter VII is dedicated to discussion comparative to literature data:

Regarding illusion perception, our results are suggestive and according to other (Ercoline, 2000; Wickens, 2006). Some of the results may lead to interesting conclusions. First, illusion perception is independent of professional experience and the flight performance. We find here a confirmation of the theory that claims that illusion perception is independent of training, as shown in other papers (Wickens, 2006). Important fact, as it shows there are no „immunities" in illusion perception and that spatial disorientation training is welcomed in any point of a flight career (Kallus, 2004). The second part of our results confirms that „non standard" reactions are not necessarily due to different perception, but also due to a lack of simulator proficiency, a similar situation being encountered by Ercoline (2000).

Regarding yaw threshold, most of our values are above the maximum theoretic threshold of 0.6 (Young and Oman, 1969) (47 of 60 subjects for aprimar and 56 of 60 subjects for areal). This was to be expected, noting our experimental setup. Additionally, we only had one run, being known that repeating exposures increased the perception.

The HEL group was the most affected in perceiving areal, while primary perception was quite good. Probably, in helicopter pilots visual component has a higher influence over spatial orientation then in other groups.

Another interesting tendency was that subsonic pilots had good detection rates. One plausible explanation is lack of prior major flight experience (7 of 10 subjects being students), let to a better coping with the simulator and less presumptions about what the simulator should do instead of actually does.

There is a difference between primary sensing and perceiving yaw. (Soyka, 2012)

Regarding the influence of motion over following a given path, we noticed a strong skewness towards right for non pilots, probably due to a lesser flight experience, pilots having both advantage of training and selection.

We followed the time to deviation, which had a normal distribution and a mean value of 114.5 seconds, with a standard deviation of 14.82 seconds (for a 0.05 p). Value is almost ten times higher than the value obtained by tracking vestibulo-ocular reflexes, so we exclude direct vestibular influence (Merfeld, 2001).
We may infer that the observed deviation is due to a lack of proper integration between vestibular and somatosensorial stimuli, a conclusion also reached by DiZio (2003), but in a different experimental setup. Centrifugal force sensed by somatosensorial receptors is higher in high speed profile, explaining the greater deviation of the later. A similar phenomenon could account for „giant hand” illusion.
Regarding the influence of spatial disorientation over UAV control, we observed that all motions have somehow affected the performance, but turbulences influenced the greatest number of subjects. Their randomness and motion over multiple axes explain the lesser adaptative response to these motions. As expected, the yaw rotation had the maximum impact on performance.
Regarding heart rate variability, we had two groups, one with high variability and other with low variability. As noted, a lesser variability is associated with sympathetical activation. A disease like diabetes, triggering vagal neuropathy, shows similar results (Malpas 1990). Most of the cases had this low variability. In our situation, where subjects have been screened are free from any nerve damage, we may conclude sympathetic activation. Regarding pNN50 which is even more sensitive in short term variability, most of cases are low variability.
Because of the literature date (Cowings, 1982; Doweck, 1997; Yokota, 2005), mostly theoretical considerations we expected a strong correlation between sympathetic activation, hence low variability and motion sickness symptoms, we have explored the differences over the profile symptoms. All the differences were insignificant, except for the OT profile.
In OT profile, F value for RMSSD is 54.78, with a minimal p, and pNN50 is more sensitive, with a superior f of 68.81. We may say it is a clear correlation between symptoms and low variability for the OT profile.
Following the first two studies, we decided to modify the producer recommended values according to the tables displayed in results section, as preprogrammed values were not satisfactory for profile demonstration over a maximal number of subjects.
The last chapter is dedicated to conclusions, mentioning here the most important ones:

1. Leans perception is independent of professional status and flight performance. There are no „immunities” regarding illusion perception. The illusion is perceived similarly by all pilots, but the way of responding to it is according to individual qualities.
2. Aprimar respects theoretical considerations, but areal is askew. HEL group was the most affected in perceiving the motion, but the primary response was rather good. There is a difference between perceived motion and primary sensation.
3. For the deviation from the flight path, we notice a rightward skewness for the non pilots. Our observed deviation is not an effect of vestibular compensation. The observed deviation could be consequence of lack of integration between proprioceptive and vestibular stimuli.
4. All motions have affected the UAV control, but turbulences have affected the greatest number of subjects (4+1 vs. 3+1 for pitch and roll). Yaw motion had the greatest impact over performance.
5. Our research followed the short time heart variability during yaw rotation, most of subjects (38 of 50) having low variability. Due to health status of all subjects, we may associate the result with sympathetic activation. In OT profile, there is a strong correlation between motion sickness symptoms and low variability.

Our whole study, consisting in leans perception, yaw motion threshold, impact over controlling real and remote operated aircrafts, the effect of yaw on heart rate variability is highly original for our country, some of the results being communicated and appreciated in international scientific manifestations (The International Congress Of Aviation and Space Medicine, Bucharest, 2011; AsMA Scientific Sessions Boston 2008, Phoenix 2010).

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