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DISORIENTATION IN VFR PILOTS: FLIGHT PERFORMANCE AND PSYCHOPHYSIOLOGICAL CHANGES DURING A FLIGHT SIMULATOR TRAINING

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Disorientation due to flying into instrument meteorological conditions (IMC) is a major safety hazard for VFR pilots (VFR: visual flight rules) as confirmed by aviation accident databases. The objectives of our research are the development and evaluation of systematic training programs to cope with different kinds of disorientation phenomena and the analysis of the psychophysiological processes during dis- and reorientation. A study was conducted using the multi-axial moveable flight simulator DISO (AMST Systemtechnik GmbH, Austria). 25 pilots were randomly allocated to one of three testing groups (one control- and two experimental training groups). The flight performance data confirm that participants with a training show better performance data in a test phase than pilots without training. The simulation scenarios are of high impact: Heart rates are clearly increased in response to more demanding segments of flight as e.g. during takeoff and landing. Analyses within the test profile "unusual-attitude recovery" demonstrate – in addition to the expected increase of heart rate due to higher mental workload – an important interaction: The increase is lower for pilots having received an unusual-attitude recovery training. First EEG results illustrate changes in the alpha- and beta band due to changing strain. To sum up, this study tries to make a contribution to basic research by analyzing psychophysiological processes as well as to applied science by emphasizing the importance and effectiveness of orientation training programs for VFR pilots.

Introduction

Disorientation due to flying into instrument meteorological conditions (IMC) is a major safety hazard for VFR pilots. Analyses of aviation accident databases confirm that in general aviation fatal aviation accidents are often classified as involving visual flight rules (VFR) into instrument meteorological conditions (e.g. Goh & Wiegmann, 2001; Véronneau & Evans, 2004).

Our concept to explain spatial and geographic orientation and disorientation bases on the model of anticipatory action regulation from Hoffmann (1993) and the model of situation awareness (SA) from Endsley (2000). "Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p. 65). Situation awareness involves a correct appreciation of many conditions. The most relevant aspects in aviation are three-dimensional spatial awareness, system (mode) awareness, and task awareness (Wickens, 2002). As correct orientation is a central factor of situation awareness, loss of orientation leads to loss of situation awareness (LSA).
The objectives of our research are the development and evaluation of systematic training programs helping to cope with different kinds of disorientation phenomena, using the multi-axial moveable (continuous yaw, limited pitch and roll) flight simulator DISO (Disorientation Trainer, AMST Systemtechnik GmbH, Austria).

In a first study, 26 jet pilots participated. The main results are that the simulator illustrates disorientation phenomena very realistically, that flight performance increases after a disorientation recovery training, and that worse performance in simulator exercises – e.g. crash during the profile "Black hole approach" – is accompanied by high physiological stress as indicated by increases in heart rate (Kallus & Tropper, 2004). Based on these results, a study was designed with adopted profiles for VFR pilots (Haug, 2003) using again the multilevel multi-method approach for the evaluation of the training effects and the analysis of cognitive, psychological and psychophysiological processes.

Method

Design and Subjects

25 VFR pilots (average age of 43 years, SD = 10.5, 23 men, 2 women, all owning a private flight license) were randomly allocated to one out of three testing groups. The experimental design is given in Table 1. Table 2 shows an overview of the flight profiles. Every participant completed three phases in the flight simulator. The nine pilots of the training group attended the awareness training ("awareness") during phase I, followed by the training with orientation- and unusual-attitude recovery exercises (phase II, "training"). The eight pilots of the awareness group also went through the awareness phase, but instead of the training phase they completed the control condition "free flight". The control group (n = 8) went

through two free flight phases instead of the training. All 25 pilots passed the test (phase III) at the end of the testing day. The simulator exercises were based on a PC7 simulation.

Table 1. *Experimental design*

	PHASE I	PHASE II	PHASE III
TRAINING GROUP (n = 9)	Awareness	Training	TEST
AWARENESS GROUP (n = 8)	Awareness	Control condition II	TEST
CONTROL GROUP (n = 8)	Control condition I	Control condition II	TEST

Table 2. *Overview of the simulator profiles*

PHASE I	
AWARENESS	**CONTROL CONDITION I**
Cockpit Instruction	*Cockpit Instruction*
Instruction flight at excellent weather conditions (WX)	*Instruction flight at excellent weather conditions (WX)*
VFR flight at min. WX, mountains	**Free Flight I**
VFR flight, mountains, clouds tilt	
Passive spin profiles: Gyrospin I and Gyrospin II	*Passive spin profiles: Gyrospin I and Gyrospin II*

PHASE II		PHASE III
TRAINING	**CONTROL CONDITION II**	**TEST**
VFR flight at min. WX, mountains, visual and VOR	**Free Flight II**	**VFR flight at min. WX, mountains**
VFR flight at min. WX, mountains, Radar Vectors		**Unusual-attitude recovery**
Unusual-attitude recovery training		

Instruction Flight. The instruction flight takes place under conditions of good visibility (about 80 km). It leads the pilot along a standardized flight path with the takeoff at Kalamata (Greece), leading to the coast, along the coast, briefly across the sea, into terrain with mountains and finally back to the airport of Kalamata. After passing the last of five turning points and before landing in Kalamata, the pilot flies two maneuvers: an aileron roll and a looping. The flight path is approximately 33 nautical miles long and it takes about 18 minutes to fly the whole circuit (including takeoff, the flight maneuvers and landing). As aid, the pilot gets a colored map of Peloponnes into which the flight path is drawn. Additionally, standardized headings are used by the instructor pilot to lead and help the pilot via radio connection. The instructor pilot also took on the tasks of an air traffic controller.

Test profile VFR flight at minimal weather conditions, mountains. This profile begins with conditions of bad visibility (10 km). It is planned to fly the same route as during the instruction flight and the pilot is explicitly instructed “to behave as in a real flight situation”. The visibility deteriorates further with time (5 km). It is overcast and the mountains are in clouds. It is not possible to fly the whole planned circuit under VFR condition. Because visibility deteriorates gradually, it is expected that not all pilots become aware of the hazard and use visual flight rules into instrument meteorological conditions.

Test profile Unusual-attitude recovery. Unusual-attitude recovery means the process of returning the aircraft to near straight and level from an unexpected bank and / or pitch angle. The exercise is drawn from jet pilots´ training courses. At the beginning of this profile, the PC7 is already airborne. After about two minutes, the instructor pilot takes over the control of the PC7 and sets certain – standardized – flight parameters via the external workstation. During the set-up time the participant inside the flight simulator keeps his eyes closed. After taking over the control from the instructor pilot, the pilot in the simulator is required to reach safe flight parameters (to recover) as fast as possible. This exercise is conducted ten times.

Procedure

The examinations lasted five to eight hours per pilot. Before and after each flight simulator phase, a two minute resting measurement (baseline, eyes closed) was conducted. After each phase (outside the simulator), the pilot took part in an extensive reconstruction interview concerning the flight profiles.

Dependent Variables

Aviation performance (observation data, instructor pilot ratings, time-measurements), psychological data (questionnaires for analyzing changes in subjective physical and psychical state, reconstruction interviews), and physiological variables (ECG, EEG, EOG, EDA) were measured.

Some results concerning the following dependent variables are reported here:

- Flight performance: observation data
- ECG: heart rate – deviation from baseline: Positive differences signify an increase in heart rate in comparison to the resting measurements.
- EEG: spontaneous activity

EEG was recorded by eight bipolar channels (positions of electrodes cf. Table 3; the ground electrode was fastened to the forehead). The electrode impedances were below 5 k ohms and the sample rate was 128 Hz. Recorded data were subject to visual inspection using the BrainVision software package of the Company Brain Products GmbH (Munich). Seconds with artefacts were excluded from further analyses. The EEG from 1 second periods were submitted to spectral analysis using the Fast Fourier Transformation (full power spectra, Hanning window). After averaging the absolute power values of the 1 seconds periods of certain sections of measurement, the data were combined to the standard bands of alpha (8-13 Hz) and beta (14-30 Hz).

Table 3: *Positions of the 16 EEG electrodes (eight bipolar channels, frontal to occipital regions*)

Channel 1	F3 - FC´3
Channel 2	F4 - FC´4
Channel 3	FC3 - PC3
Channel 4	FC4 - PC4
Channel 5	C3 - P3
Channel 6	C4 - P4
Channel 7	P´3 - O1
Channel 8	P´4 - O2

The rate of missing EEG-data is beyond five percent for each channel (due to continuously artifacts – e.g. muscle activity – or technical problems). No missing EEG data have been replaced and to lose no additional data, only univariate analyses (power of only one channel) have been calculated.

Results

Flight Performance

During the test phase (VFR flight at minimal weather conditions, mountains), the pilots of the control group caused the highest number of crashes [Pearson-Chi^2 (df=2, n=25) = 10.96, p = .004, Figure 1]. Figure 2 illustrates that pilots of the training group show the tendency to enter the cloud layer less often than participants of the other two groups [Chi^2 (df=2,n=25) = 4.99, p = .102].

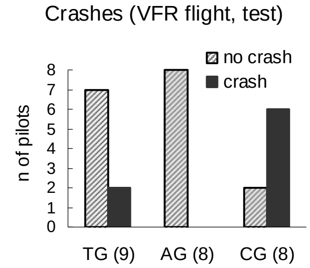

Figure 1. *Crashes during the VFR flight of the test phase separate for pilots of the training group (TG), awareness group (AG), and control group (CG).*

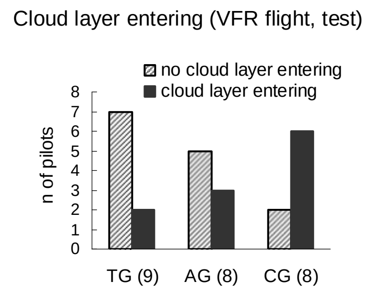

Figure 2. *Cloud layer entering during the VFR flight of the test phase for pilots of the training***-** *(TG), awareness***-** *(AG) and control group (CG)*

Heart Rate

Concerning the instruction flight at the beginning of the testing day, the results of the two-factorial ANOVA for repeated measures with the between factor testing group exhibit a strong main effect of the section of measurement [F(15.2,319.4) = 21.4, p = .000]. (There are neither differences between the testing groups nor is there an interaction.). As illustrated in Figure 3, the different tasks within the flight are clearly reflected in the heart rate (beats per minute, deviation from baseline). In average, the heart rate is always above the baseline. The least stressful sections are about between 90 seconds after the takeoff and 30 seconds before the first flight maneuver (role). The first strong increase of the heart rate occurs before the takeoff; descriptively the beginning of the ascent can be observed 30 sec. before the takeoff (TO), statistically (Tukey HSD post hoc tests, p < .05) it becomes significant 10 sec. before TO. When the aircraft is safely airborne, the heart rate decreases quickly within 30 seconds; the whole decrease takes about 90 sec. The flight maneuvers aileron role and looping are also reflected in the heart rate. Already 80 sec. before the landing (touchdown), there is a strong increase in the heart rate which reaches a maximum between the range of 10 sec. before and 10 sec. after the touchdown, followed by a rapid decrease within 20 seconds.

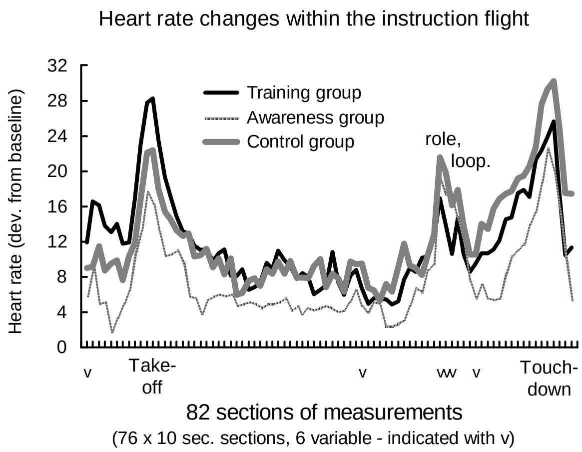

Figure 3. *Heart rate changes (beats per minute – deviation from baseline, means) separate for the three testing groups (TG: n = 8, AG: n = 8, CG: n = 8)*

Concerning the heart rate, no differences occur between the three testing groups during the flight profiles of the first two phases in the simulator.

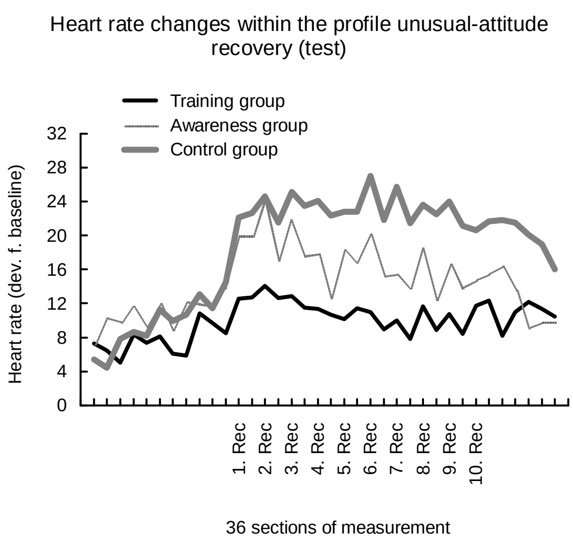

Figure 4. *Changes in the heart rate (beats per minute – deviation from baseline, means) during the test profile unusual attitude recovery (ten recoveries) for the three testing groups (training group: n = 9, awareness group: n = 7, and control group: n = 7); each recovery exercise takes about 13 seconds, the whole profile about 12 minutes.*

Within the test profile unusual-attitude recoveries, there is a clear interaction between the section of measurement and the testing group [F(17.7, 176.7) = 2.4, p = .002, Tukey HSD post hoc tests] in addition to the main effect section of measurement [F(8.8, 176.7) = 12.2, p = .000, Figure 4]. While there are no group differences at the beginning of the profile (before flying the ten recoveries), the increase of the heart rate is much higher in the control group than in the training group.

EEG – Unusual-attitude recoveries (test phase)

As analyses illustrated no differences between the three testing groups and for some calculations group sizes were too low, the factor testing group has not been involved in the following calculations. In a first step the absolute power of the EEG during waiting with closed eyes for the command to recover from an unexpected attitude (10 x 8 seconds, closed eyes), was compared with the EEG during the resting measurements before and after the test phase (each two minutes, eyes closed).

Table 4. *Average power (µV-Square) in the alpha- and beta band during the resting measurement before the test phase (RM5, 2 min., closed eyes), the time while waiting with closed eyes for the command to recover within the test profile unusual-attitude recovery (Bef. Rec., 10 x 8 sec.) and the resting measurement after the test phase (RM6), and the results of the ANOVAs*

ALPHA	RM5 (M)	Bef Rec. (M)	RM6 (M)	n	ANOVA	p-value
F3 - FC´3	2.6	2.1	3.1	17	F(2.0,32.0)=2.9	.070
F4 - FC´4	3.0	2.4	3.6	18	F(1.3,21.6)=5.7	.019
FC3 - PC3	16.5	7.9	16.5	18	F(1.4,23.1)=10.1	.002
FC4 - PC4	17.4	8.0	19.5	19	F(1.1,20.6)=9.0	.005
C3 - P3	23.7	14.5	23.0	19	F(1.7,30.2)=9.2	.001
C4 - P4	20.6	12.4	20.5	19	F(1.6,29.5)=9.1	.002
P´3 - O1	38.4	40.9	44.1	20	F(1.3,23.8)=0.5	.517
P´4 - O2	40.9	39.1	42.8	19	F(1.3,23.4)=0.7	.451

BETA	RM5 (M)	Bef Rec. (M)	RM6 (M)	n	ANOVA	p-value
F3 - FC´3	1.3	1.8	1.6	14	F(2.0,26.0)=1.2	.326
F4 - FC´4	1.2	1.5	1.3	16	F(1.3,19,.6)=1.0	.342
FC3 - PC3	4.3	3.6	4.5	15	F(2.0,28.0)=3.4	.049
FC4 - PC4	4.1	3.4	4.2	17	F(1.4,23.1)=2.7	.103
C3 - P3	4.1	3.6	4.2	16	F(2.0,30.0)=1.3	.291
C4 - P4	3.8	3.5	3.6	17	F(1.9,30.6)=0.5	.584
P´3 - O1	5.2	5.3	5.3	19	F(1.7,30.6)=0.1	.938
P´4 - O2	5.1	5.4	5.1	18	F(1.2,21.1)=0.3	.615

The results demonstrate no changes in the absolute power of the alpha band at the parieto-occipital positions P´3-O1 and P´4-O2. But concerning all other measurement positions (frontal to parietal), the alpha occurring during anticipating the recovery exercises is clearly decreased compared to a resting measurement. For the beta band, a low decrease at FC3-PC3 could be detected (Table 4).

In a second step, the periods before recovering (10 x 8 seconds, closed eyes) and during recovering (10 x 5 seconds after controls have been handed over from the instructor pilot to the participant in the simulator, eyes opened) were compared. As expected, there are of course very big decreases in the alpha band – especially over posterior regions, but at the two anterior channels, there are no changes in the alpha band. Concerning the beta band, there is a significant increase of power at F3-FC´3 and decreases at posterior regions.

Table 5. *Average power values (µV-Square) in the alpha- and beta band while waiting with closed eyes for the command to recover (Bef. Rec., 10 x 8 sec.) and while recovering (Rec. 10 x 5 sec. after controls have been taken over), and the results of the T tests*

ALPHA	Bef. Rec. (M)	Rec (M)	Diff	df	t	p-value
F3 - FC´3	1.8	1.9	.2	13	.6	.548
F4 - FC´4	2.0	1.7	-.3	13	-1.2	.259
FC3 - PC3	8.0	2.6	-5.5	14	-2.5	.026
FC4 - PC4	7.5	2.3	-5.2	14	-2.3	.037
C3 - P3	11.3	2.0	-9.4	15	-2.8	.013
C4 - P4	1.3	2.1	-8.2	15	-2.5	.026
P´3 - O1	35.8	3.2	-32.5	16	-3.1	.007
P´4 - O2	36.1	3.5	-32.7	15	-2.9	.011

BETA	Bef. Rec. (M)	Rec (M)	Diff	df	t	p-value
F3 - FC´3	1.2	1.7	**.5**	11	2.9	**.015**
F4 - FC´4	1.3	1.6	.3	13	1.3	.220
FC3 - PC3	2.8	2.6	-.2	12	-.8	.423
FC4 - PC4	3.5	2.3	-1.2	13	-2.0	.071
C3 - P3	3.5	2.4	-1.1	14	-2.9	.012
C4 - P4	3.5	2.1	-1.4	14	-2.2	.042
P´3 - O1	5.2	3.0	-2.2	16	-3.2	.005
P´4 - O2	5.3	3.0	-2.3	14	-3.9	.002

Discussion

The results of the flight performance data confirm positive training effects, especially for the test profile "VFR flight at minimal weather conditions, mountains". Pilots with a training behave less risk prone, whereas pilots without any kind of orientation training do often not turn back at an appropriate moment. They enter the cloud layer more frequently and lose orientation, which finally can lead to a crash into the mountain or into the ground by trying to stay under the cloud layer without realizing that the mountains are in clouds. This happened despite the fact that the pilots had a map (including the geographical data of the region etc.), that they had flown the route already under conditions of good visibility (instruction flight), and that they always had the possibility to get weather information from the "air traffic controller" (i.e. form the instructor pilot at the external work station of the simulator). As many accident reports, this fact highlights the problem of deteriorating visibility conditions: Some VFR pilots do not recognize the ensuing danger which can lead to fatal crashes, even in regions well known to the pilots.

The simulation scenarios are of high impact for the pilots, as could be demonstrated by the changes in the heart rate. As example the data of the instruction flight have been presented. The clear increases caused by the takeoff and the landing procedure are similar to the published results concerning changes during flight (e.g. Hankins & Wilson, 1998; Wilson, 2002). Veltman (2002) compared psychophysiological reactions during simulator and real flight and could confirm similar results for heart rate, heart rate variability, and respiratory frequency.

Our analysis of the heart rate within the test profile unusual-attitude recovery demonstrates the expected increase of heart rate due to increasing mental workload. Additionally, the results illustrate a significant lower increase of the heart rate for pilots having received an unusual-attitude recovery training. As a conclusion, the effects of the evaluated training program can be described as increasing flight performance together with reducing stress in demanding flight situations. First EEG results show changes in the alpha- and the beta bands due to changing strain in the simulator.

To sum up, this study makes a contribution to basic research by analyzing psychophysiological changes as well as to applied science by emphasizing the importance and effectiveness of orientation training programs for VFR pilots.

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