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# Anticipatory Processes in Critical Flight Situations

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## ANTICIPATORY PROCESSES IN CRITICAL FLIGHT SITUATIONS

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The model of anticipatory behavior control of Hoffmann (2003) is a current concept to describe the central role of anticipatory processes. It extends and changes the focus of the situation awareness concept to describe spatial disorientation. Two simulator studies have been conducted including the exercise black hole approach – a difficult landing procedure at night – with different samples of pilots. Pilots were grouped according to their flight performance in this profile (crash, problems, landing). Results of the heart rate show a significant interaction between the recording sections within the approach and the performance group. Already some miles before the crash point, the increase of heart rate is stronger for pilots who crash-landed. These results indicate that crashed pilots exhibit higher stress levels at the beginning of the landing procedure. This is interpreted as a reflection of subconscious anticipatory processes. Increased awareness about their state should have allowed at least a touch and go maneuver or the decision of flying a go-around.

Keywords: Anticipatory behavior control, situation awareness, spatial disorientation, black hole approach

### Introduction

In this paper, attention is focused on the basic principle of anticipation to explain spatial orientation in flight and thus the role of erroneous anticipation as cause for critical flight situations such as spatial disorientation.

#### Anticipatory behavioral control

A current concept to describe the role of anticipatory processes is the model of Hoffmann (1993, 2003). His psychological learning framework of anticipatory behavioral control includes assumptions of elderly theories such as the ideo-motor theory (e.g. James, 1890, as citied in Stock & Stock, 2004) and the reafference principle of von Holst and Mittelstaedt (1950).

The model of Hoffmann addresses learning in situations, in which behavior is goal-oriented instead of being stimulus driven. As depicted in Figure 1, it considers a primary action-effect reinforcement as well as a secondary differential action-effect learning based on relevant situational cues. In a given situation "S", a voluntary action "$A_{volunt}$" is based on an anticipated effect "$E_{ant}$". If the behavioral effect ("Effect") meets the anticipation, the action is reinforced and the loop is closed. In case of a mismatch, corrective action is necessary. Anticipatory processes take place on different levels of information processing and on different levels of central nervous organization – starting from unconscious anticipatory eye-movements and ending with complex conscious planning processes. The majority of anticipatory processes is established unconsciously and based on basic learning processes, which are also not necessarily related to a conscious understanding of the situation.

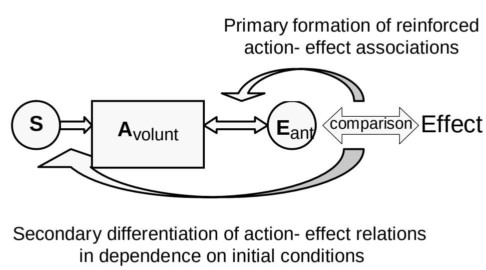


***Figure 1.*** Illustration of the model of anticipatory behavioral control (Hoffman, 2003, p. 54); explanations cf. text below.

#### Anticipatory behavioral control and situation awareness

The model of anticipatory behavioral control extends and changes the focus of the common concept of situation awareness (SA). "Situation awareness is supposed to be an essential prerequisite for the safe operation of any complex dynamic system" (Sarter & Woods, 1991, p. 45). Endsley (1988, p. 97) defines SA as "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." According to this definition, SA involves the perception of critical factors in the environment (Level 1), the understanding (interpretation) of those factors, particularly in relation to goals (Level 2), and the understanding of what will happen with the system in the near future (Level 3). SA describes the cognitive state of the operator.

An attempt to explain how the traffic picture of air traffic controllers is maintained (or lost), led to an integration of Hoffmann's concept of anticipatory behavioral control (1993, 2003) and the concept of SA. The resultant "situation awareness loop" stresses the central role of anticipatory processes for the concept of SA (Kallus, Barbarino, & Van Damme, 1997, Figure 2). The situation awareness loop is based on qualitative data from the Integrative Task Analysis project (ITA; Kallus, Barbarino, & Van Damme, 1998), in which more than 100 controllers from different ATC positions in 12 European ATC centers were interviewed. This model strengthens the role of anticipatory processes in SA.

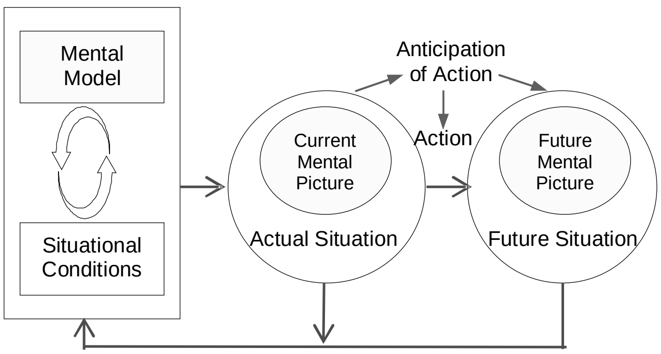


***Figure 2.*** Situation Awareness Loop (Kallus, Barbarino, & Van Damme, 1997, modified).

**Anticipation and spatial orientation**

To obtain spatial orientation, different kinds of conscious and subconscious sensory information are used. Cheung (2004) gives an overview of the spatial orientation mechanisms in flight. At the conscious level for example, focal vision is used for object recognition and reading the flight instruments and other symbolic data. Thus, conscious processing requires interpretation and intellectual construction from available information (top-down process). At a subconscious level, ambient vision is used for visual guidance in positioning and orienting. Subconscious cues are utilized for detection of angular and linear acceleration, including gravity. The tactile and proprioceptive cues support inertial force and linear acceleration detection. "Neural processing in the CNS includes integration and interpretation of these sensory inputs and their comparison with internal models. These internal models are formulated based on past experience and training, which, in turn, generate expectations concerning estimation of the current motion, position, and attitude of the aircraft. Finally, the execution of the intended motor command occurs in response to current perception of aircraft motion" (Cheung, 2004, p. 39). This view implies that non aware anticipatory processes should be considered explicitly as the prospective role of anticipatory processes play a key role. The processes described by Cheung do not just "generate expectations concerning estimation of the current motion" but they also, and probably even to a much higher degree, produce anticipations of future motion, position, and attitude of the aircraft including the effects of one's own planned flight behavior (output commands). Thus, the pilot generates an anticipated (future) mental picture of the future attitude etc. This anticipated mental picture is compared with the perceived inputs. If this comparison between the two pictures fits, spatial orientation is maintained. Thus, correct anticipations, which guide the pilot's actions, play a central role for spatial orientation. If the comparison between the to pictures does not fit, spatial disorientation can occur. Spatial disorientation in aviation is defined as a "state characterized by an erroneous sense of one's position and motion relative to the plane of the earth's surface" (Gillingham, 1992). This phenomenon is due to interferences in the perception or false interpretation of visual, vestibular, and / or somatosensory cues. Spatial disorientation is classified into three different types (e.g. Bellenkes, Bason, & Yacavone, 1992; Cheung, Money, Wright, & Bateman, 1995; Parmet & Gillingham, 2002):
Type I: Unrecognized spatial disorientation,
Type II: Recognized spatial disorientation,
Type III: Incapacitating or overwhelming spatial disorientation.

These different types of spatial disorientation phenomena have in common that the anticipation of the future state of the system is disturbed – in many instances based on misperceptions and / or illusions from the vestibular systems. These processes are mostly unaware and slip in the information processing system, which results in a wrong mental representation of the current and future state of the system. Awareness might not be more than the tip of the iceberg of processes, which contribute to spatial disorientation. A broad range of sub aware processes which govern psychomotor coordination in motion contribute to our understanding how and which information is misprocessed or which psychological or physiological processes lead to spatial disorientation. The model of spatial orientation and motion-sickness by Bles (1998) is one example of mostly unaware processes, which contribute to spatial disorientation.

How are missing fits between anticipations and outcomes perceived and used by pilots for safe and effective operation? Which misfits are tolerated and when is a pilot about to lose orientation? Is there some information available, which might be used to improve the diagnosis of misfits and can this be used to improve training procedures?

Two studies with different research questions and different samples of pilots were conducted. The results concerning the exercise black hole approach are reported here.

**Method of Study I**

The first study was conduced with the motion based simulator "AMST AIRFOX® Spatial Disorientation Trainer" (AMST Systemtechnik GmbH, Ranshofen, Austria). The flight profiles were based on a F-16 simulation.

To evaluate the efficiency of a spatial disorientation-recovery training, 26 military jet pilots with the mean age of 33.5 years (SD = 9.6) and an average flight experience of 2216 flight hours were randomly allocated to one of three experimental groups (Kallus & Tropper, 2004). All pilots attended a test in the simulator with profiles including situations likely to induce spatial disorientation. One of the five test profiles was the "black hole approach".

The black hole approach is a night flight profile without peripheral visual cues, except very few lights at the airport. At the beginning, the F-16 is already airborne and 14 nautical miles away from the airport. The pilot gets the instruction to come in for a full stop landing. During the straight in approach, spatial disorientation phenomena can occur. As a result of the hardly lighted airport, the runway can appear to move (but „in reality" the airplane begins to move sideways, up and down). Above this, pilots can get the visual illusion of a high-altitude final approach and if they believe their illusion and do not look at or do not trust the instruments, especially the altimeter, they decline too fast which causes a crash a few miles in front of the runway.

ECG recordings were taken from thorax leads. Heart rate (beats per minute, corrected for baseline) and heart rate variability (as MSSD = mean square of successive differences) were calculated. As baseline, the heart rate (beats per minute ) of six two-minutes baseline recordings in the simulator with eyes closed was used. Differences to this baseline were calculated for further heart rates analyses - positive differences signifying an increase of the heart rate, negative ones a decrease in comparison to the baseline.

For the analyses of the black hole approach, ECG data of 21 pilots were available. The pilots were grouped ex post according to their flight performance into three groups: crash (n=5), problems (n=6), and landing (n=10). "Problem" means that the pilot had a bad landing (for example outside the runway), he did a touch and go maneuver, or he decided to fly a go-around.

The average duration of the profile black hole approach was about seven minutes, including booting up the program by the instructor pilot and the preparation for taking over the control of the airplane. To create comparable sections of measurement, the following four events (four markers within the file of the physiological data) were used:

- Start of the profile (pilot is not flying yet).
- Handing-over the control of the airplane from the instructor pilot to the pilot within the simulator (14 miles away from the runway).
- 10 miles out (out = remaining distance to runway).
- Landing (touch on runway), crash, or problem (landing before or beside the runway, touch followed by a climb instead of the full stop landing, decision to use the ejector seat, or start of a go around maneuver without touching the runway).

These four markers were the basis for forming offline 13 sections of measurement. Ten of these sections are of the same duration for all pilots and three are variable to compensate the different times needed by the pilots to complete the whole profile without losing any ECG data.

For heart rate analysis, a two-factorial univariate ANOVA was carried out, using the procedure GLM (general linear model) with the repeated measure factor "section of measurement" and the between factor "performance group." Repeated measures effects were analyzed with the F-value of Huynh-Feldt. The clearly non-normal distributed heart rate variability was analyzed with non-parametric methods (Kruskal-Wallis test, Mann-Whitney U-test, Friedman test, Wilcoxon test)

**Results of Study I**

The results of the ANVOVA demonstrate an interaction between the factor performance group ($k = 3$: landing, crash, problems) and the repeated measures factor section of measurement ($l = 13$), $F(11.7,105.7) = 2.0$, $p = .031$. The heart rate increases in all pilots before reaching the runway [mean effect "section of measurement: $F(5.9,105.7) = 16.3$, $p < .001$], but as can be seen in the interaction illustrated in Figure 3, after a nearly identical average heart rate at the beginning of the profile, the increase is much bigger in pilots causing a crash, than in the other two performing groups.

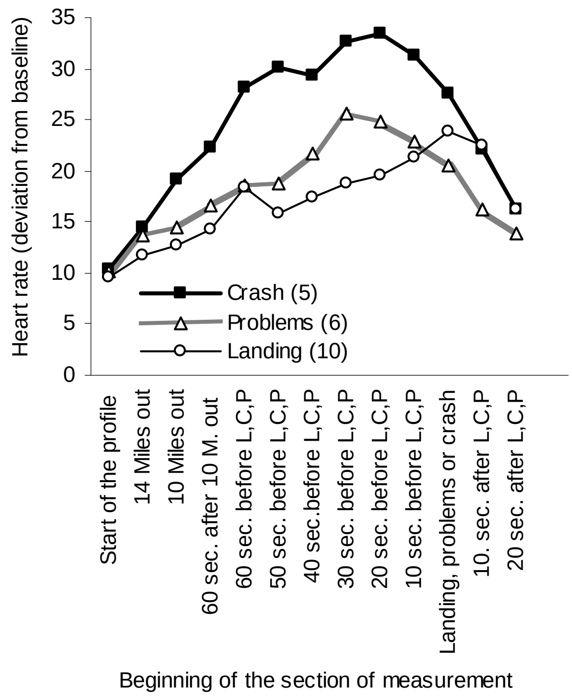


***Figure 3.*** Changes in the heart rate (means, deviation from baseline) in the course of the profile black hole approach for three performance groups crash, problems, and landing.

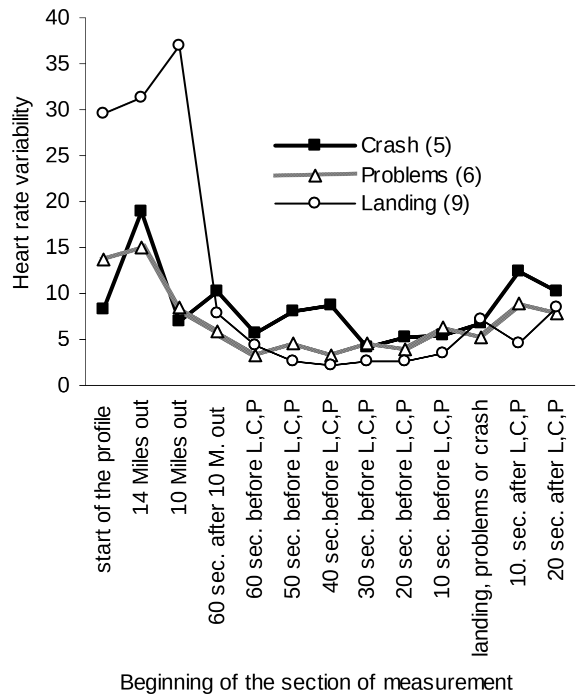


***Figure 4.*** Changes in the heart rate variability (medians) in the course of the profile black hole approach for the three performance groups.

Analyzing the heart rate variability also indicates significant changes within this profile, Chi-square (n = 20, df = 12) = 77.7, $p < .001$. Group effects (results of Mann-Whitney U-Tests with $p \leq .05$) could be detected at the beginning of the profile, where pilots with good landings show higher variability values than pilots who got problems. About 40 seconds before touch-down, pilots with good landing have smaller heart rate variability values than pilots causing a crash.

**Method of Study II**

For the second study, the fixed based "AMST AIRFOX® Spatial Disorientation Trainer" Mock-up simulator was used. The flight profiles were based on a PC-7 simulation. Participants of the study were Private Pilots and Professional Pilots (Commercial Pilots License or Aircraft Transport License). One of the flight simulator profiles was again the black hole approach. At the beginning of the profile, the PC-7 was already airborne and 11 nautical miles away from the runway. For statistical analyses, the pilots were grouped ex post according to their flight performance into two groups: crash (n=5) and landing (n=10). The five crashes happened between 3 miles and 1 mile in front of the runway.

To analyze changes in the heart rate within the black hole approach, 10 sections of measurement were used and they were based on the distance to the runway. For the inference statistical analyses (ANOVA), the first seven sections of measurements (10 to 3 Miles out of the runway) were used.

**Results of Study II**

The results of the ANVOVA show a significant interaction between the factor performance group (k = 2: landing and crash) and the repeated measures factor section of measurement (l = 7), $F(14,16) = 2.4$, $p = .047$ (Zauner, 2006). As can be seen in Figure 5, already 10 Miles out of the runway, the heart rate of pilots who crashed is increased compared to the heart rate of pilots who landed .

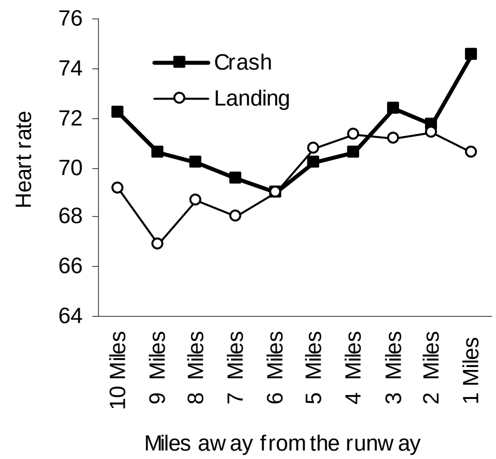


***Figure 4***. Changes in the heart rate (beats per minute, means) in the course of the profile black hole approach for the two performance groups crash and landing.

**Discussion**

The reported results indicate that the demands within the simulator profile black hole approach and the flight performance are reflected in the heart rate. Crashed pilots show a stronger anticipatory increase of psychophysiological arousal than pilots with a good landing. The time course is different in the two studies due to the fact that quite different aircraft (jet vs turbo-prop) were simulated. Nevertheless striking differences appear in the anticipatory period. This indicates different anticipatory processes for the two groups. Increased awareness about the psychophysiologically refleced state should have allowed at least a touch and go maneuver or the decision of flying a go-around.

Crashed pilots seem to anticipate more problems than the non-crashed. Why do they not respond adequately? Do they not correctly recognize their own anticipations? If this interpretation holds true new options for improving training procedures by psychophysiological recordings and feedback as well as option to improve reconstruction methods emerge. This suggests that awareness of problem situations should be further increased by improved awareness training including "self awareness". On the theoretical side the results strengthen the central role of anticipations as primary processes in spatial orientation. A broad range of these anticipations need not be aware and need not be understood by the pilots. This implies that the key components of the situation awareness model and the methods to assess situation awareness need to be supplemented by methods, which reflect the anticipatory processes.

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