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Training for prediction and management of complex and dynamic flight situations

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Abstract

This study proposes and evaluates a systemic method for *ab initio* pilot training for prediction and management of complex and dynamic flight situations. Complex flight scenarios were simulated for training in a network of flight simulators. The new training program was evaluated with forty student pilots assigned to an experimental and a control group in a pre- and post-test design. The results show that student pilots can learn complex multitasking skills from the very beginning of their flight instruction. Greater amount of training leads to better learning results. In addition, the multitasking skills could be transferred from simulated to real flight.

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Keywords: systemic perspective; multitasking; automaticity; pilot training; simulator training; network of flight simulators

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1. Multiple control and multitasking

The aviation system is a complex system in which unsafe interactions among pilots and air traffic controllers can lead to hazards. Uncoordinated control actions of multiple controllers can arise for different reasons, such as misconception of the situation, miscommunication between controllers, unclear responsibility and authority, rash control under pressure to precede other controllers, or confusion (Takuto, Leveson, Thomas, Fleming, Katahira et al., 2014). Thus, controlling their own aircraft is not the biggest challenge for pilots. They also have to coordinate

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safely their control actions with those of other controllers in the system, to apply procedures and to find solutions for uncertain or not well defined situations.

Monitoring and predicting the complex flight situation are prerequisites of being a part of the system and coordinating with other aircraft. The training philosophy established many decades ago was to learn control of the aircraft and add progressively new tasks, such as navigation, radio communication and so on. The acquisition of higher order skills is considered to be the result of flight experience and training received after the *ab initio* instruction. Price and Salas (1998) show that pilots achieve higher levels of situational awareness which enables them to predict the development of a situation primarily throughout flight experience and licenses which follow after the *ab initio* training. In their study General Aviation pilots with an average flight experience of 700 hours were described as passive receivers of information. Airline pilots with an average of 6,000 flight hours were actively involved in seeking information. Flight examiners with an average of 12,000 flight hours were concerned with understanding and predicting complex relationships among the situational elements. Furthermore, research has shown that pilots do not always apply the rules necessary for coordination with other aircraft in collision situations (Koglbauer, Braunstingl, Haberkorn & Prehofer, 2012; Haberkorn, Koglbauer, Braunstingl & Prehofer, 2013) and more practical training is necessary to address these facts.

Although coordination is so important for pilots, unfortunately it is not systematically trained, but only addressed towards the end of the *ab initio* practical flight training which lasts for 45 hours. In the beginning flight instructors tend to perform the strategic coordination tasks by themselves and allow the student pilots to concentrate on the control of their own aircraft. Thus, student pilots do not monitor the whole situation, they are not required to take decisions and miss valuable learning opportunities. Learning the control of an aircraft poses by itself multitasking demands on the student pilots. For example they have to use and interpret the instruments and the controls, to interpret the aircraft's attitude relative to the horizon, to determine their position using reference cues on the ground, to handle the engine and the configuration of the aircraft for different phases of flight and many other part tasks.

The aviation system has changed dramatically and nowadays there are more complex procedures and much higher traffic density which pose higher multitasking and coordination demands on pilots. These demands will be further increased after the implementation of new air traffic management concepts proposed by the Single European Sky Air Traffic Research System in Europe (SESAR, 2009; SESAR, 2012), and the Next Generation Air Transport System in North America (NextGen, 2012). Future pilot tasks will include the cooperation and the increased responsibility for self-separation in the system (Hoermann et al., 2011). These new conditions and challenges make a new approach to the *ab initio* pilot training necessary. Thus, new niches for the aviation industry are created to develop solutions and meet future human resources and safety demands. Flight instructors raise questions about the right time and method to address the complex coordination training issues. The answer is not trivial, notwithstanding that there is a lack of research on this topic so far.

Whole-task performance requires different skills than the performance of the part-tasks such as attention control and allocation skills. In a study with Air Force cadets Gopher, Well and Bareket (1994) investigated the training effects of a strategic computer game, the Space Fortress. They used two training approaches. One group of cadets trained the whole task at all times, and the focus of their attention was directed by the experimental set-up on different aspects of the game. A second group of cadets trained with the emphasis-only training, which used in the beginning part-tasks in simple games. The complexity of the game increased gradually and integrated more tasks. The results show that both training approaches were beneficial for the cadets, but the whole task training leads to significantly higher game scores. The cadets could transfer the whole-task skills gained with both training approaches to real flight, but these two training approaches did not lead to different levels of flight performance. However, both training groups performed significantly better in real flight than a control group which did not train with the computer game. The cadets who trained with the computer game were more likely to graduate than the control group.

In this study a naturalistic training environment is proposed: a network of flight simulators. Many skills can be trained in the simulator because it is less dangerous, less expensive, and the appearance of certain events can be controlled (Farmer, Van Rooij, Riemersma, Jorna and Moraal, 2003; Koglbauer, Kallus, Braunstingl & Boucsein, 2011). Simulator networks have been successfully used in the military aviation (Schreiber et al., 2011), and in training of airlines' ground operations (Georgiou et al., 2013). Farmer et al. (2003) argued that the effectiveness of simulator training depends on the similarity between the simulated task and the real task. Furthermore, Kallus (2009) showed that several factors such as the simulator features, the mental models and the experience of the trainees contribute to the outcome of the simulated task. The transfer of simulated instrument flight to instrument and visual flight was investigated by Pfeiffer, Horey and Butrimas (1991) with student pilots transitioning from a single engine turboprop aircraft to a turbojet aircraft. The performance in the simulator was significantly correlated with performance during instrument flight rules flight ($r = 0.72$, $N = 9$) and visual flight rules flight ($r = 0.62$, $N = 9$), showing a positive transfer of training from simulator to real flight.

This study evaluates the learning processes during a whole-task training which was performed in a network of flight simulators. Complex flight scenarios have been recorded during real flight and simulated for training in a network of flight simulators. The student pilots were trained to control the aircraft on the ground and in the air and to coordinate with other air vehicles according to the regulatory procedures and to the clearances given by air traffic controllers. The focus was on "being a part of the system" and the instructors provided feedback whenever the omissions or errors of the flight students had implications for the safety and efficiency of the system.

According to Fitts and Posner (1967) and Andersen (1983) learning is a three-stage process. In the cognitive or declarative phase the trainees have to remember declarative facts about the skill domain, to correctly interpret them and decide what they should do. In the associative phase the trainees develop procedural patterns of connected actions and begin to detect and correct their own errors. They are primarily concerned with perfecting the action patterns. In the autonomous stage the performance of the procedure requires less attention and cognitive control. The learning pattern of complex skills was described by Schmidt and Lee (1999) as a change towards less involvement of the cognitive skills and greater involvement of automatic processes.

1.1. Research questions

The main research question is to determine if student pilots can progress in learning whole-task coordination strategies at the beginning of their practical training. The question is not whether such a training program is sufficient, but if a learning pattern can be recognized.

The second question addresses the transfer of multitasking skills from the network of flight simulators to real flight.

2. Method

2.1. Participants

Forty *ab initio* student pilots (13 women, 27 men) aged between 20 and 32 years (mean $M = 25.43$ years, standard deviation $SD = 0.5$ years) participated to the experiment. They were informed about the purpose of the experiment and signed an informed consent form. The student pilots were randomly assigned to a training (22 student pilots) and a control (18 student pilots) group.

2.2. Procedure

The evaluation experiment consisted of four trials: simulator pre-test (1.5 hours), simulator training (3 hours), simulator post-test (1.5 hours) and real flight test (1.5 hours). The difference in the group treatment was in the training phase. The training group performed complex scenarios and the control group performed navigation and low visibility procedures for visual flight. However, both groups could train during the pre- and post-tests and received feedback from the instructor.

Each flight trial included the following phases: taxi on the ground, take-off, departure, cruise, approach, landing and taxi. Data from real flight was recorded and several representative scenarios were reconstructed for the network of flight simulators. These resulted in semi-structured complex scenarios: a part of the traffic and simulated radio communication with the air traffic controller was predetermined and there was space and time for two trainees in the network of flight simulators to fit in. During all these flight phases the trainees could communicate with the controller and they had to follow his instructions and coordinate with other air vehicles. They did not communicate with other pilots, but they listened to the communication of other pilots with the controllers. Therefore the trainees could hear the positions, intentions and instructions received by other pilots. The trainees could see the positions of other air vehicles on a tablet computer (Fig. 1) and on the visual screen of the simulator.

In addition, the trainees could use the tablet application illustrated in Fig. 1 to see their own position depicted as an aircraft icon at the bottom of the display, the map, the airspace structures depicted as magenta fields and frames, as well as the reporting points (dark blue text and markers) and traffic patterns for the runway in use and the transition routes to the traffic pattern (cyan lines). The student pilots could draw their cleared route on the app (green line). On the ground the app displayed a taxi chart, the position of the own aircraft and the positions of other air vehicles.

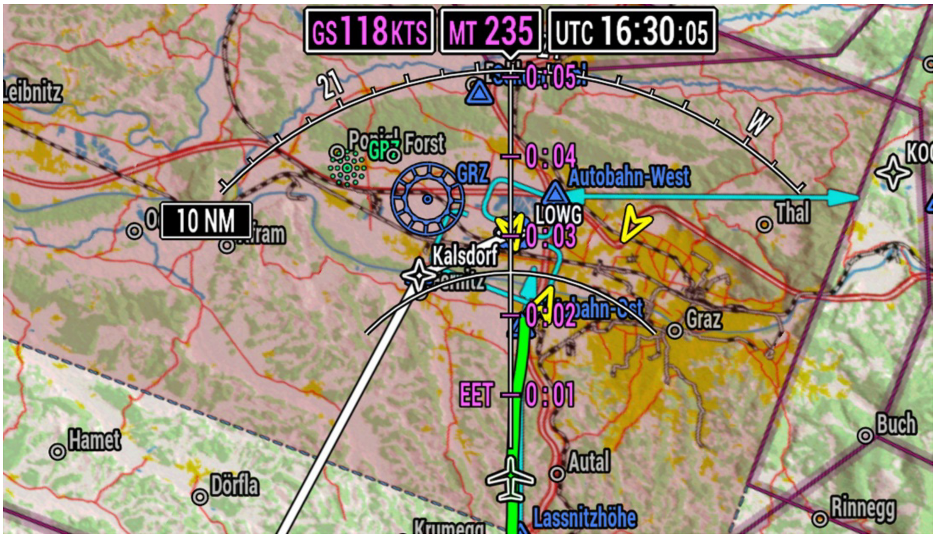

Fig. 1. An example of a complex flight situation as depicted on the screen of the tablet computer during training.

The network of flight simulators included two flight simulators and several robot aircraft within the same airspace. The trainee flew with an instructor in a generic fixed-base light aircraft simulator with genuine cockpit, controls and side-by-side seats (Simulator 1). The multiple channel vision system has a cylindrical screen of 7 meters diameter and 3 meters height which covers a horizontal angle of 190 degrees. A second flight simulator (Simulator 2) with a second trainee and instructor was connected to the network and interacted with the trainee from the Simulator 1 in a pre-defined manner.

During the real flight tests the student pilots flew with a flight instructor in the Aquila A210, a light training aircraft with side-by-side seats. All flights took place inside and outside the control zone of Graz Airport (LOWG).

2.3. Dependent measures

The student pilots were asked to rate their learning process for multitasking and for the part-tasks. They rated their agreement with statements describing processes for each learning stage (cognitive, associative, autonomous) using a scale ranging from (-5) very little to (+5) very much. In addition the kinematic data of all air vehicles involved were recorded in the network of flight simulators. However, for space reasons the analysis of kinematic data cannot be presented here.

2.4. Data analysis

An analysis of variance with repeated measures was performed to evaluate the effects of training on the students' self-reported learning processes. The *within-subjects* factor had two levels (simulator pre-test and simulator post-tests). The *between-subjects* factor had two levels (training and control group). Pearson's coefficient of correlation (r) was calculated to evaluate the transfer of training from simulator to real flight. The alpha was set at 0.05.

3. Results

3.1. The cognitive stage

Figure 2 illustrates the learning stages of the training and the control group in the simulator pre-test and post-test. The average cognitive effort of the student pilots was lower in the post-test (M = 0.09, SD = 0.30) as compared to the simulator pre-test (M = 1.92, SD = 0.27), differences being statistically significant [F(1,37) = 47.93, p < .0001, η² = 0.56].

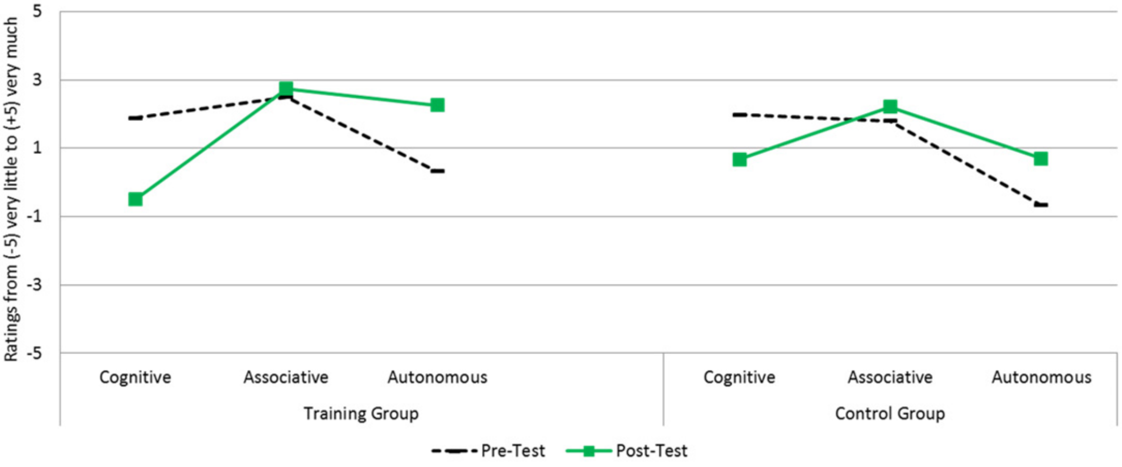

Fig. 2. Learning stages of the training and the control group in the simulator pre-test and post-test.

The interaction term between test and group reached statistical levels of significance [F(1,37) = 4.08, p < 0.05], showing that the training group scored lower in cognitive effort than the control group in the simulator post-test. The *between-subjects* factor did not reach statistical significance for the level of cognitive effort.

3.2. The associative stage

The perfecting of actions increased from the simulator pre-test (M = 2.15, SD = 0.15) to post-test (M = 2.47, SD = 0.17), but the differences failed to reach statistical significance [F(1,38) = 3.16, p < .083, η² = 0.07]. The interaction term between task and group did not reach statistical levels of significance. The training group had slightly higher overall scores (M = 2.62, SD = 0.17) than the control group (M = 2.00, SD = 0.19). The *between-subjects* factor accounted for 13% of the variance [F(1,38) = 5.68, p < .02, η² = 0.13].

3.3. The autonomous stage

The scores of automaticity increased from the simulator pre-test (M = -0.17, SD = 0.26) to post-test (M = 1.48, SD = 0.21). The *within-subjects* factor accounted for 64% of the variance [F(1,38) = 66.31, $p < .0001$, $\eta^2 = 0.64$]. The interaction term between task and group reached statistical levels of significance for automaticity [F(10,380) = 13.25, $p < .002$]. As illustrated in Figure 3, the training group scored higher than the control group in the automaticity of multitasking, avoidance of frontal and lateral collisions, overtaking, coordination with other aircraft in the traffic circuit and on the ground, building and maintaining a mental picture of the airport procedures and of the traffic situation, airspace monitoring and listening to the radio communication. The control group scored higher than the training group only in the automaticity of flying the own aircraft. The training group obtained higher overall scores for automaticity (M = 1.21, SD = 0.29) than the control group (M = 0.02, SD = 0.32). The *between-subjects* factor accounted for 19% of the variance [F(1,38) = 8.79, $p < .005$, $\eta^2 = 0.19$].

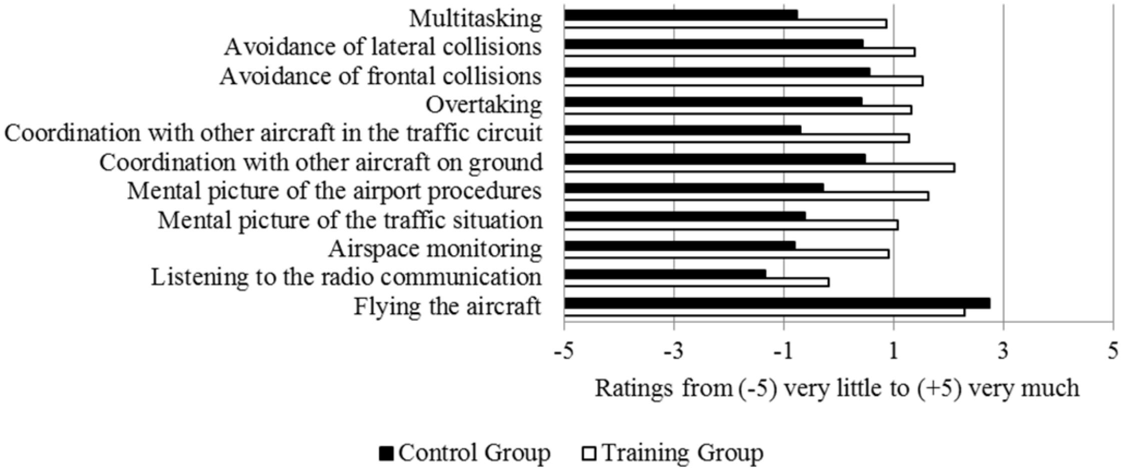

Fig. 3. Mean ratings of automaticity in performing whole- and part-tasks of the training and of the control group.

3.4. The transfer to multitasking skills to real flight

As Fig. 4 shows, the scores of cognitive effort (r = 0.63, $p < .0001$) and automaticity (r = 0.60, $p < .0001$) for multitasking in simulator post-test correlate significantly with the scores in real flight, showing a positive learning transfer from simulator to real flight.

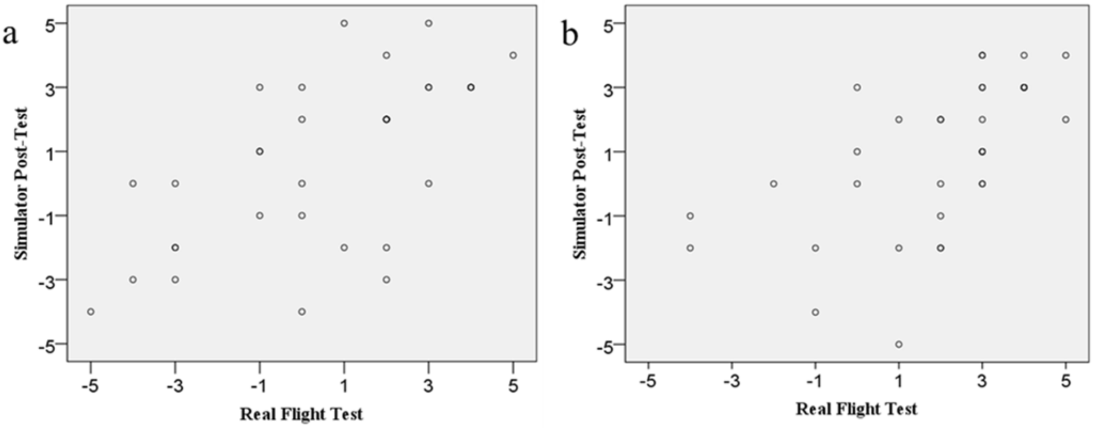

Fig. 4. Scatterplots of cognitive effort (a) and automaticity (b) of multitasking scores in simulator post-test and real flight test.

A significant positive correlation between the simulator post-test and the real flight test scores was found also for perfecting the multitasking (r = 0.42, p < .007). All correlations were calculated using data from 34 student pilots (N = 34) who completed the real flight test at the time of evaluation.

4. Discussion

This study evaluated the learning processes of student pilots during a whole-task training which was performed in a network of flight simulators. The student pilots were trained to monitor the flight situation and to coordinate with other air vehicles according to the regulatory procedures and to the clearances given by air traffic controllers. The focus was on “being a part of the system”.

The evaluation experiment consisted of four trials: simulator pre-test, simulator training, simulator post-test and real flight test. The difference in the group treatment was in the training phase. The training group performed complex scenarios and the control group performed other flight tasks. However, both groups could train during the pre- and post-tests and received feedback from the instructor.

The main research question was to determine if student pilots can progress in learning whole-task coordination strategies at the beginning of their practical training. An overview of the learning patterns of the student pilots is presented in Fig. 2.

It is noteworthy that both groups showed lower levels of cognitive effort and higher levels of automaticity in simulator post-test and compared to the simulator pre-test, as shown by significant *within-subjects* effects. This means that the student pilots could learn already during the first session in the pre-test.

What is the outcome of three extra hours of whole-task training received by the training group? The results show significant changes in the learning pattern of the training group. The concern with declarative facts typical for the cognitive stage of learning was significantly reduced in the training group as compared to the control group. Although the main concern of the student pilots from the training group is with perfecting their performance, this group reported significantly higher scores of perfecting and automaticity than the control group. Furthermore, the training group scored higher than the control group in the automaticity of multitasking, avoidance of frontal and lateral collisions, overtaking, coordination with other aircraft in the traffic circuit and on the ground, building and maintaining a mental picture of the airport procedures and of the traffic situation, airspace monitoring and listening to the radio communication. The control group scored higher than the training group only in the automaticity of flying the own aircraft.

The second research question addressed the transfer of multitasking skills from the network of flight simulators to real flight. The results show that lower cognitive effort during multitasking in the simulator post-test was associated with lower cognitive effort during real flight. There was also a positive linear relationship between perfecting of multitasking in simulator post-test and real flight. Higher automaticity of multitasking in the simulator post-test was associated with higher automaticity during real flight. Thus, the transfer of multitasking skills from simulator to real flight could be confirmed using a similar method like Pfeiffer et al. (1991).

In can be concluded that student pilots can begin at an early stage of their flight training in a network of flight simulators to learn monitoring, coordinating and performing multiple tasks simultaneously. The multitasking skills trained in the network of flight simulators could be transferred to real flight. However, this kind of training should be continued for the whole duration of the *ab initio* instruction in real flight. The student pilots are still perfecting their performance and can learn from new situations which occur during their instruction. If the flight instructors use a large part of the training time performing the strategic coordination by themselves and allowing the student pilots to concentrate only on the control of their own aircraft, the students will miss valuable learning opportunities.

This research shows how the *ab initio* pilot training could improve and better prepare the future pilots to coordinate their actions in the aviation system and take more responsibility for self-separation. These will be essential tasks of the pilots in the future aviation system (Hoermann et al., 2011; SESAR, 2009; SESAR, 2012; NextGen, 2012).

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