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Simulator training improves the estimation of collision parameters and the performance of student pilots

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Abstract

Mid-air collisions are among the top ten leading causes of fatal General Aviation accidents. The separation between two aircrafts is a process which depends on multiple dynamic interactions between pilots. This study presents the design and experimental evaluation of a feedback-based training program for ab initio student pilots to anticipate collision parameters and to select appropriate avoidance manoeuvers. The new training programme was evaluated with sixteen student pilots in the flight simulator. The results show that the student pilots significantly improved the accuracy of their estimation of time to collision and their performance in selecting the collision avoidance manoeuvers.

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Keywords: systemic perspective; anticipation of time to collision; collision avoidance; flight training; simulator training; student pilots

1. The challenge of collision avoidance in visual flight

Collision avoidance is a basic responsibility of pilots flying according to visual flight rules (VFR). Either for work or for leisure purposes, there is a variety of air vehicles which can be encountered in VFR flight such as power-driven light or ultra-light airplanes (e.g. helicopters, gyrocopters) and lighter-than-air vehicles (e.g. gliders, balloons and airships). VFR pilots gather information about conflicting air vehicles primarily by monitoring the surrounding airspace or by listening to the radio communication between pilots and air traffic controllers. VFR pilots are

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responsible for deciding whether an avoidance manoeuver is necessary and for selecting and performing a collision avoidance manoeuver in a timely manner.

Unfortunately the aviation safety reports show that mid-air collisions are among the top ten leading causes of fatal General Aviation accidents (FAA, 2015). Collision avoidance during visual flight is a difficult task because it requires both the anticipation of a collision before it occurs and the performance of coordinated control actions within limited time and space. Pilots' anticipation of mid-air collisions and avoidance actions significantly influence the flight safety and the performance of the whole aviation system. From the systemic perspective collision avoidance is a process of multiple and dynamic control. The international regulations (ICAO, 2005) established the "right-of-way" rules for VFR flight which pose constraints on the individual control actions and which consider the particular manoeuverability features of different categories of air vehicles. According to the international rules (ICAO, 2005) the collision avoidance manoeuver depends on the types of air vehicle involved in the conflict and on the conflict geometry. In head-on conflicts each pilot shall manoeuver the aircraft to the right for avoiding a collision. In a laterally converging conflict the pilot who has the other aircraft on its right side shall give way and manoeuver behind the conflicting air vehicle. From the latter rule exceptions are air vehicles which are lighter-than-air (e.g. an airship, glider or balloon) which have the right-of-way even if they are approaching a power-driven, heavier-than-air aircraft from the left. The pilot who has to give right-of-way shall avoid passing over, under or in front of the other air vehicle. Furthermore, a pilot who is overtaking an aircraft shall change his direction to the right.

Various traffic displays and collision warning systems have been introduced to assist VFR pilots in the perception of collisions (Haberkorn, Koglbauer, & Braunstingl, 2014; Haberkorn, Koglbauer, Braunstingl, & Prehofer, 2013). However, research has shown that even when a conflict is detected, pilots' estimation of the time to collision is cognitively demanding and error-prone (Koglbauer, Braunstingl, Haberkorn, & Prehofer, 2012; Koglbauer, 2015). In addition, the accident reports and studies in the flight simulator have shown that pilots do not always adhere to the rules in their collision avoidance manoeuvers. Pilots confronted with head-on collisions in the flight simulator manoeuvered in all directions: upwards, downwards, to the left and to the right (Haberkorn et al., 2013; Koglbauer et al., 2012). Thomas and Wickens (2005) reported the preference of pilots for vertical evasive manoeuvers in head-on and lateral conflicts with approach angles of less than 120°. Only in 55% of cases pilots avoided to the right. Several studies confirm a preference of pilots for vertical collision avoidance manoeuvers (Abbott, Moen, Person, Keyser, Yenni & Garren, 1980; Merwin & Wickens, 1996; O'Brien & Wickens, 1997; Wickens & Morphew, 1997; Gempler & Wickens, 1998; Wickens & Helleberg, 1999; Helleberg, Wickens & Xu, 2000, Alexander & Wickens, 2001).

Pilots' non-adherence to the rules of the air is dangerous, because their non-action or uncoordinated avoidance actions may lead to a mid-air collision. For example, two pilots who descend at the same time in a head-on conflict can still collide. If each pilot adheres to the rules and turns to the right in a timely manner they can achieve separation. Potentially unsafe interactions of control actions between two controllers were analyzed by Takuto, Leveson, Thomas, Fleming, Katahira et al. (2014). In their example the controllers were technical devices. In this study the controllers are the student pilots. Takuto et al. (2014) identified causal scenarios for unsafe actions from the systemic perspective and stated that each controller should have a model of the other controller as well as a model of the controlled process. The model for collision avoidance in VFR flight is contained in the rules of the air (ICAO, 2005). However, so far there are no means for VFR pilots to train the complex skills of collision anticipation and avoidance in a systematic manner. Student pilots learn the rules of the air in theory lessons, but receive no formal practical training on applying these rules.

In summary, the analysis of empirical data and safety reports shows that pilots have difficulties in anticipating collision situations and in adhering to the rules in their collision avoidance manoeuvers. In this study a training program for student pilots was developed and evaluated with the intention to improve their anticipation of collisions and their adherence to the rules in selection of avoidance manoeuvers.

2. The training concept

The training concept has a twofold aim: to improve the anticipation and rule-conforming avoidance action of student pilots. Flight simulation and an application on a tablet computer were the media chosen for the training.

The cognitive skills to anticipate changes which can potentially lead to hazards are critical in aviation. According to the model of anticipatory behavioral control the comparison between anticipated and actual sensory input is the basic learning mechanism for the formation of mental models of actions (Hoffmann, 2003). The accuracy of the anticipations can be adjusted by comparison between the predicted model and the perceived picture of the situation (Kallus, 1997). Research shows that anticipation-based simulator training was effective for improving pilots' anticipatory processes and actions of pilots in recovering the aircraft from various critical states such as unusual attitudes, full stalls and spins (Koglbauer et al., 2011). Research shows also that the perception of time can be improved by feedback (see Koglbauer, 2015). Based on previous research a new training concept for collision anticipation and avoidance was developed.

The student pilots received a written briefing about the right-of-way rules, as well as drawings which explained the dynamics of different conflict geometries and the application of the right-of-way. The practical training included both collision and non-collision scenarios in the flight simulator. Collision scenarios were head-on, lateral and overtaking conflicts. The traffic information which is usually provided by the air traffic controller (e.g. type of air vehicle, relative position, altitude and direction of motion) was verbally announced by the instructor. Traffic was visible on the visual scenery of the flight simulator and displayed on an application for tablet computers. The trainees were instructed to report as soon as they decided if the traffic was in conflict or not. The simulation was frozen and the student pilots estimated the time to collision and the distance which separated them from the conflicting traffic. They received immediate feedback from the instructor about the real time to collision and the distance which separated them from the intruding aircraft. Consequently, the student pilots reported their selected avoidance action. If the selected avoidance manoeuver was not correct, the instructor explained the rule again and the dangers of uncoordinated manoeuvers between pilots. In the end all student pilots performed only rule-conforming avoidance manoeuvers.

2.1. Research Hypotheses

The first research hypothesis was that feedback-based training in the flight simulator would improve the accuracy of time to collision estimations of student pilots.

The second research hypothesis stated that simulator training would improve the accuracy of distance estimations of student pilots.

The third hypothesis was that simulator training would improve the performance of student pilots in selecting the rule-conforming collision avoidance manoeuvers.

3. Method

3.1. Participants

Sixteen *ab initio* student pilots (6 women, 10 men) aged between 21 and 32 years (mean = 25 years, standard deviation = 3 years) participated at the experiment. They were informed about the purpose of the experiment and signed an informed consent form.

3.2. Procedure

The evaluation experiment consisted of two trials. Each trial included two non-collision and four collision scenarios presented in a random order. The conflicting air vehicles were a light aircraft in a head-on geometry, a light aircraft converging from the right, a glider converging from the left and a light aircraft flying slower in the same direction and at the same altitude. For the standardization of the traffic geometries the autopilot was engaged at the beginning of each scenario.

The training program was conducted in a generic fixed-base light aircraft simulator with genuine cockpit, controls and side-by-side seats. 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. The traffic was visible on both the visual screen of the flight simulator and on a tablet computer. The cruise speed of the flight simulator was 125 knots (232 km/h) at 70% power.

3.3. Dependent measures

The ratios of subjective to objective time and distance were chosen as measures of accuracy (Koglbauer, 2015). The estimations of time to collision and of the distance to the conflicting aircraft and the objective data provided by the traffic generator were used to calculate the ratio of subjective to objective time to collision and the ratio of subjective to objective distance. In addition the instructor rated students' selection of the collision avoidance action. Performance ratings ranged from 0 (low) to 4 (high) and reflected the conformity to the rules of the air of the collision avoidance action selected by the student pilot.

3.4. Statistical analysis

An analysis of variance with repeated measures was performed to evaluate differences in the accuracy of time and distance estimations and differences in performance between the first and second trial of the experiment. The statistical hypotheses were tested at alpha 0.05.

4. Results

4.1. The accuracy of the time to collision estimations

As illustrated in Fig. 1, the average ratios of subjective to objective time to collision decreased significantly in the second trial, showing that the accuracy of students' estimation has increased [$F(1,15) = 15.36$, $p < 0.001$]. The trial accounted for 50% of the variance [$\eta^2 = 0.50$]. The first hypothesis was confirmed at alpha 0.05. The descriptive results are presented in Table 1.

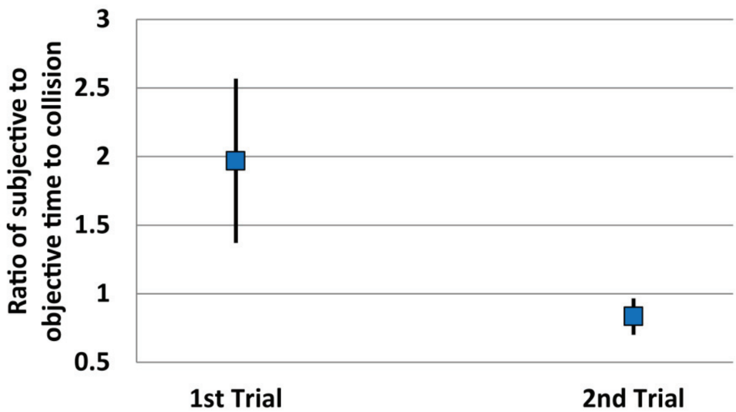

Fig. 1. Mean ratios of subjective to objective time to collision and 95% confidence intervals.

4.2. The accuracy of the distance estimations

The average ratios of subjective to objective distance decreased in the second trial (Table 1), but differences did not reach statistical significance [$F(1,15) = 3.97$, $p < 0,065$, $\eta^2 = 0.21$]. Thus, the second hypothesis was not confirmed at alpha 0.05.

4.3. The selection of the avoidance manoeuvers

As illustrated in Fig. 2, the performance of student pilots in selecting the collision avoidance action has improved significantly in the second trial [$F(1,15) = 13.25$, $p < 0.002$]. The trial accounted for 47% of the variance [$\eta^2 = 0.47$]. The third hypothesis was confirmed at alpha 0.05. The descriptive results are presented in Table 1.

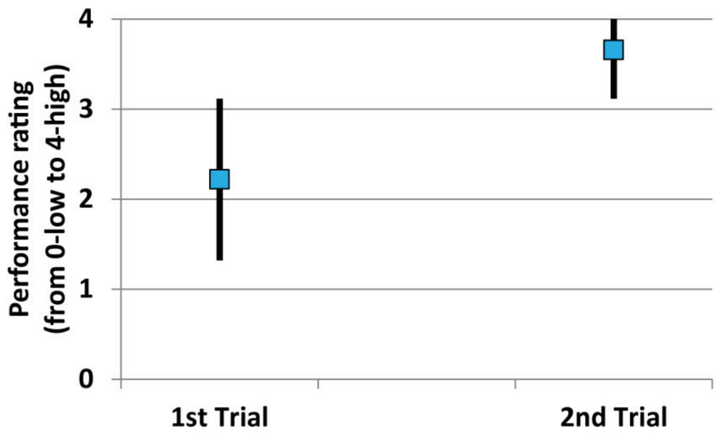

Fig. 2. Mean performance scores for the selection of the avoidance manoeuver and 95% confidence intervals.

Table 1. Descriptive results

Dependent measure	Mean	Standard deviation	Confidence interval 95%	
			Lower limit	Upper limit
Ratio of subjective to objective time to collision (1st trial)	1.97	0.28	1.37	2.57
Ratio of subjective to objective time to collision (2nd trial)	0.84	0.06	0.70	0.97
Ratio of subjective to objective distance (1st trial)	2.16	0.31	1.50	2.82
Ratio of subjective to objective distance (2nd trial)	1.52	0.14	1.22	1.83
Performance ratings (1st trial)	2.22	0.42	1.32	3.12
Performance ratings (2nd trial)	3.67	0.25	3.12	4.20

5. Discussion

Although mid-air collisions are among the top ten leading causes of fatal General Aviation accidents (FAA, 2015) student pilots do not receive practical training in the anticipation and avoidance of midair collisions. The empirical data and aviation safety reports show that pilots have difficulties in anticipating collision situations and in adhering to the rules in their collision avoidance manoeuvers. The lack of rule-conforming control actions or the provision of multiple, uncoordinated control actions of different pilots can lead to hazards which affect the safety of the whole system.

In this study a simulator training based on the framework of anticipatory behavioral control was developed and evaluated with sixteen student pilots. The first research hypothesis was confirmed, showing that feedback-based training in the flight simulator significantly improved the accuracy of time to collision estimations of student pilots. In the first trial the students estimated that the time to collision was in average two times longer than the objective time. They actually had less time than they thought to perform the collision avoidance manoeuver. In the second trial the average ratio of subjective to objective time to collision was in average 0.84, showing a significant improvement in the accuracy of time to collision estimation. In the second trial the student pilots underestimated slightly the time to collision, a phenomenon reported also in licensed pilots and drivers (see Koglbauer 2015 for a review).

The second research hypothesis was not confirmed. Although the student pilots could improve the accuracy of their distance estimations, the difference between trials did not reach statistical significance at alpha 0.05.

The third hypothesis was confirmed. The results showed that simulator training significantly improved the performance of flight students in selecting the rule-conforming collision avoidance manoeuvers. In the first trial some students had problems to remember the rule or they thought that applying the rule would lead to a collision in particular cases. Especially the avoidance behind the conflicting air vehicle in lateral conflicts can be counter-intuitive for the students who do not understand the dynamics of the conflict. For example when an aircraft is approaching from the right the student pilot has to turn to the right in order to avoid a collision. Some student pilots would have preferred turning to the left. However, after they practiced the rule-conforming avoidance actions the student pilots were able to remember and perform the collision avoidance manoeuvers correctly.

As the results show, the cognitive skills necessary to anticipate and act in collision situations can be improved with specific simulator training. The comparison between anticipated and perceived information was effective in improving the accuracy of time to collision estimations of student pilots. The student pilots improved their ability to anticipate and avoid mid-air collisions. Flight simulation is an environment in which student pilots can safely learn the demanding mental skills to anticipate collisions and to select rule-conforming avoidance actions. The performance of rule-conforming collision avoidance actions in a timely manner contributes to the safety of the whole aviation system.

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