Spatial Disorientation Training in the Rotor Wing Flight Simulator

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BACKGROUND: This study is intended to identify efficacy, evolving applications, best practices, and challenges of spatial disorientation (SD) training in flight simulators for rotor wing pilots.

METHODS: Queries of a UK Ministry of Defense research database and Pub Med were undertaken using the search terms 'spatial disorientation,' 'rotor wing,' and 'flight simulator.' Efficacy, evolving applications, best practices, and challenges of SD simulation for rotor wing pilots were also ascertained through discussion with subject matter experts and industrial partners. Expert opinions were solicited at the aeromedical physiologist, aeromedical psychologist, instructor pilot, aeromedical examiner, and corporate executive levels.

RESULTS: Peer review literature search yielded 129 articles, with 5 relevant to the use of flight simulators for the spatial disorientation training of rotor wing pilots. Efficacy of such training was measured subjectively and objectively. A preponderance of anecdotal reports endorse the benefits of rotor wing simulator SD training, with a small trial substantiating performance improvement. Advancing technologies enable novel training applications. The mobile nature of flight students and concurrent anticollision technologies can make long-range assessment of SD training efficacy challenging. Costs of advanced technologies could limit the extent to which the most advanced simulators can be employed across the rotor wing community.

DISCUSSION: Evidence suggests the excellent training value of rotor wing simulators for SD training. Objective data from further research, particularly with regards to evolving technologies, may justify further usage of advanced simulator platforms for SD training and research.

KEYWORDS: spatial disorientation, rotor wing, flight simulator.

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Spatial disorientation (SD), the incorrect perception of one's physical orientation in space, can occur even in highly experienced pilots. Despite advances in technology, the proportion of fatal mishaps associated with spatial disorientation and SD accident rates remains relatively unchanged over time.[8] According to a recent 10-yr review, 11% of serious rotor wing flight accidents, i.e., resulting in at least $50,000 or at least 1 d of work absence,[1] were linked to SD.[7] It is also established that SD is more likely to occur in rotor wing versus fixed wing pilots.[10,14] A myriad of preventative measures have been employed to counter SD. Flight instrument use and dedicated aeromedical instruction are longstanding countermeasures governed by NATO requirements. The Barany chair, which instils suspicion of 'seat of the pants' piloting, is a staple across international aeromedical training. The UK Army's helicopter SD program is particularly robust, with issuance of SD educational pilot manuals, the use of a disorientation trainer, and in-flight SD demonstrations. In an effort to deliver more interaction, realism, and transfer to flight, high fidelity simulators are being increasingly harnessed for SD training.

In the 1920s the aviator was blindfolded inside the 'Ruggles orientator,' a primitive three plane of motion flight simulator, 'so that the sense of direction [could] be sensitized without the assistance of the visual cues.'[6] In contrast, modern simulators leverage six planes of motion, wide fields of view, and complex imagery to generate an immersive experience. It is understood

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that simulation must be used to train SD countermeasures such as reliance upon instruments, workload management, and crew communication given the immutability of the human vestibular response. The use of flight simulators to train rotor wing pilots about SD has been assessed internationally through subjective and objective measures. Challenges and best practices have been noted by instructors, aeromedical experts, and industrial partners. Evolving practices such as multiship simulations, enhanced cuing, interoperability, and consideration of unmanned aerial platforms are rapidly emerging.

METHODS

Measures of efficacy, evolving applications, best practices, and challenges to implementation were assessed in a literature review. Queries of a UK Ministry of Defense research database and Pub Med were undertaken using the search terms 'spatial disorientation,' 'rotor wing,' and 'flight simulator.' Best practices, challenges, and evolving applications of SD simulation were also ascertained through discussion with subject matter experts across the UK Ministry of Defense, UK industrial partner QinetiQ, the U.S. Department of Defense, and U.S. industrial partner NASTAR Center. Expert opinions were solicited at the aeromedical physiologist, aeromedical psychologist, instructor pilot, aeromedical examiner, and corporate executive levels. In particular instructor pilots and simulation experts at Royal Naval Air Station Yeovilton were interviewed at length regarding higher level architecture (HLA), interoperability, and advanced cuing as evolving technologies.

RESULTS

Peer review literature search yielded 129 articles, with 5 relevant to the use of flight simulators for the spatial disorientation training of rotor wing pilots. Efficacy of such training was measured subjectively and objectively. A preponderance of anecdotal reports endorse the benefits of simulator SD training, with a small trial substantiating performance improvements. Johnson et al. demonstrated favorable student assessment of SD training in the UH-60 flight simulator in their survey of 30 pilots.[12] All participants in this study rated the 18 U.S. Army Aeromedical Research Laboratory simulator scenarios as good to excellent in terms of realism, effectiveness, agreement with measures able to be undertaken to counter SD, and agreement that preventive measures would work. In 2004, the Indian Air Force evaluated 10 helicopter crews undergoing 60 min of SD demonstration in a simulator with a continuously rotating yaw mechanism, simulating three illusions.[15] The majority of aircrew reported an improvement in their awareness of SD phenomena to be very good or excellent after the course. From September 2004–May 2005, the use of the UK Griffin helicopter flight simulator for SD training was assessed at Royal Air Force (RAF) base Shawbury.[11] There were 19 students who underwent 5 interactive spatial awareness scenarios and were formally evaluated by instructor pilots in comparison to 18 controls. Students trained in SD rated their training favorably and trended toward improved performance compared to controls. A second UK rotor wing trial conducted at RAF Shawbury between January 2006–January 2007 assessed level of situational awareness, detection and rectification of all problems, realization of potential consequences, delegation of nonflying tasks, and communication with copilot.[11] The nine students who had received the additional flight simulator training demonstrated significantly improved simulator test performance as measured by instructor pilots compared to controls ($P < 0.01$), with a trend toward decreased near and actual controlled flight into terrain (CFIT) in these students. For each simulator scenario assessed in this trial, 89–100% of students believed that an identical scenario could happen in actual flight and a vast majority of SD trained students made a favorable assessment of the training. In a larger trial at RAF Benson, 1 of 12 SD scenarios were incorporated into 72 rotor wing refresher training sorties conducted within Chinook, Puma, and Merlin flight simulators from September 2008–Decembers 2009.[9] Of the aircrew, 74% stated that the sortie made them feel uncertain about orientation and 97% judged the experience and debrief made them better prepared for the situation in actual flight.

Despite a paucity of objective data on efficacy, anecdotal reports and an intuitive sense for the value of flight simulators for SD training has led to increased training demand, driving numerous technological breakthroughs in this field. Advanced technologies serve to increase the realism of the simulation and improve transfer of learned skills to actual aircraft flight. These include wide field of view, computer generated GPS imagery, centrifuge motion systems to generate sustained Gs, and motion cuing for weapons effects, sling load, troop deployment, and ground contact.

Planes of motion capability has advanced from rotational modes alone (yaw, pitch, and roll) to the translational modes of surge (forward movement), sway (lateral movement), and heave (vertical movement). Most modern day simulators are designed to be able to move in six independent directions, each referred to by engineers as a degree of freedom (DoF), enabling each of the previously stated planes of motion, with a 'seventh' degree of freedom occasionally used to characterize centrifuge arm G forces.

Computer algorithm scenario generation enhances interaction, reduces training variation, and enables optimum selection of SD predisposing conditions. Advanced HLA includes the networking of multiple simulators to enable collective training for multicrew, multiship operations, and tasks such as formation flight, cross platform encrypted frequency hopping communications, and coordination of time, space, and weapons and laser employment (Nick Wharmby, Test Pilot, Inzpire Ltd; personal communication; 15 February 2016). Other computer graphic technologies that may be developed include the simulation of low lying fog, wiper failure, rain on the canopy, the creation of cloud gaps, discharge of flares, and shifting helicopter landing zone markers.

In addition to nonvisual cues such as vibration, some simulators are capable of introducing smoke as part of a distraction to predispose toward the SD condition (Nick Wharmby, Test Pilot, Inzpire Ltd; personal communication; 15 February 2016). Motion platforms in themselves have not been empirically proven to be more effective than nonmotion platforms for SD training. Theoretically, motion would not contribute substantially toward development of an SD scenario given the predominance of visual predisposing factors in the development of SD. However, one expert has noted decrements in the performance of students who progress from nonmotion simulators to actual flight given a higher cognitive load when contending with the novel sensation of motion (Rick Leland, President, The National AeroSpace Training and Research Center, Environmental Tectonics Corporation; personal communication; 20 November 2015). Another instructor noted that pilots training in motion simulators maintained better situational awareness with glide slope compared to students training in the same tasks in the nonmotion flight simulator (Rick Smart, RNAS Flight Instructor; personal communication; 22 March 2016).

The highest U.S. Federal Aviation Association (FAA) certification for flight simulators, the D level certification, requires specific advanced features which are useful in creating high fidelity SD training; these features include mechanical vibration of flight and realistic frequency and amplitude of flight deck noises.[7] The most advanced commercial motion systems include the Desdemona and U.S. Navy Kraken (Angus Rupert, M.D., Ph.D., U.S. Army Aeromedical Research Lab; personal communication; 13 June 2016). The Desdemona is mounted on a fully gimballed structure that is able to rotate around any axis. These system allows 2 m of vertical movement, combined with 8 m along a horizontal sledge with the sledge also capable of spin. A centrifuge arm enables this simulator to generate the constant G forces which may be encountered in advanced rotor wing attack helicopters.[5] Advanced simulators are also capable of interoperability with regards to other flight simulators as well as with flight simulator software.

Aeromedical researchers and rotor wing instructors have posited a number of best practices with regard to the use of simulators for SD training in rotor wing pilots. In particular, the use of advanced technologies, the use of reality based scenarios, the student debrief, the delivery of refresher training in the flight simulator platform, and the use of the flight simulator to conduct aeromedically relevant research have all been proposed as best practices. Multiple experts have called for the employment of real world mishap scenarios in order to amplify the training effect.[2,4,12] Such reality based scenarios have indeed been rated as effective by students,[4,12] with interactive techniques as a whole rated as far better than isolated demonstration.[9–11] Allowing the student to be in control of all the tasks with no instructor involvement increased their confidence in their ability to deal with unexpected situations.[11] Student debriefing further enables the student to reinforce learning and gain awareness of important aspects of training which may have escaped them during the scenario.[11] Technologies which enable video playback of the training scenario may further improve the quality of the debrief.[13] The availability of simulator SD refresher training and the use of SD training when transitioning to a new aircraft have also been proposed as beneficial and have been favorably rated by students.[4] Aeromedical research into SD training may enable identification of more precise physiological parameters associated with the development and resolution of SD, thereby enabling the development of highly effective, physiologically validated scenarios. The use of the flight simulator to train rear crewmembers and unmanned aircraft pilots are still developmental in nature.

Challenges to implementation of rotor wing simulator SD training include simulator, instructor, student, training, and fiscal factors. The acquisition of advanced trainers does not always take the cost of maintenance and software updates into account. Instructors may have varying ability to teach and integrate SD scenarios if defined algorithms are not used. Operational constraints may limit time for SD training when other types of training are prioritized. Military students, by virtue of constant rotation and turnover, are a challenging long-term research population, making it difficult to assess long-term training efficacy. Most current SD simulator training programs do not address nonflight air crews or unmanned aircraft student populations.[11] In the absence of controlled longitudinal research, it would be challenging to ascertain decreases in SD mishaps associated with training improvements and those associated with improvements in anti-collision technological advances.

DISCUSSION

Spatial disorientation remains a potentially fatal aeromedical problem. High fidelity simulators afford realistic, interactive SD training. Although efficacy is mostly characterized by anecdotal reports, technological and training practices are evolving to deliver more realistic SD training for rotor wing pilots, a population particularly at risk for SD. Best practices have been implemented based on anecdotal evidence, perceived likelihood of transfer of skills into actual flight, and an intuitive sense of what constitutes effective training. Further research can help validate the best practices for simulator SD training for rotor wing pilots, particularly with regards to areas of controversy such as the use of motion platforms. GPS imagery and intraoperability provide exciting opportunities to train pilots across allied nations within authentic operating environments. In order to justify broad usage of costly high technology simulators it is important for the aeromedical community to continue research efforts in this field.

In conclusion, technology surrounding flight simulators is rapidly evolving to support enhanced SD training efforts, particularly within the rotor wing community. Follow-on research will enable validation of what are currently perceived as best practices and may elucidate new applications which have not been considered previously. Preservation of human life and financial cost savings related to SD prevention make a strong argument for continued investment into research and technology regarding SD simulator training in the high-risk rotor wing population.

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