

A Novel Immersive Approach for Spatial Disorientation Training

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ABSTRACT

Spatial disorientation (SD) remains a significant cause of accidents for military pilots. Despite technological advancements in flight displays and instrumentation, increasingly complex workloads can place pilots in situations where they find themselves relying primarily on sensory cues, leading them to question their aircraft displays and misjudge actual aircraft orientation (Lewkowicz et al., 2020). Continuous training has been identified as an effective approach to guide pilots to accurately respond to SD (Pennings et al., 2020). However, continuous training requires training methods that are not resource intensive, provide rich information, and most importantly, are engaging (Sitzman et al., 2018). Current SD training methods often address one of the requirements making continuous training difficult to achieve. For example, traditional classroom training can lack the necessary engagement (Lawson et al., 2017) while controlled live training in an aircraft is limited by instructor availability, aircraft availability, safety considerations, and cost. These issues lead to a need in the training environment to provide an economic, low footprint, and portable solution without compromising engagement to combat the current SD training limitations. The current work will discuss benefits and limitations of current SD training approaches, the types of physiological measures that can be used to provide rich data related to SD illusions, and the design of a novel training tool integrating virtual reality, galvanic vestibular stimulation (GVS), and physiological metrics to provide a realistic SD experience that commensurate with a convincing flight environment.

ABOUT THE AUTHORS

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technical capabilities and the real-world needs of Aptima's customers. Dr. Weil holds a PhD and MA in cognitive/experimental psychology from The Ohio State University with specializations in quantitative psychology, cognitive engineering, and psycholinguistics. He previously received a BA from Binghamton University. Dr. Weil is a member of the Human Factors and Ergonomics Society, the American Psychological Association, the Cognitive Science Society, and the National Defense Industrial Association. In 2023 he was chosen to serve on the AIAA (American Institute of Aeronautics and Astronautics) SciTech 2024 Guiding Coalition.

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INTRODUCTION

Aviation mishaps are costly events that can have severe consequences for both military operations and personnel. These incidents often result in the loss of or damage to expensive weapons systems, such as the destruction of an F-16 fighter jet due to a mechanical failure or a helicopter crash caused by pilot error resulting in multiple casualties and significant property damage. Mishaps frequently lead to fatalities or serious injuries, including disabilities, affecting not only the involved personnel but also the morale and efficiency of the entire unit. One notable cause of aviation mishaps is spatial disorientation (SD), which is recognized as the leading cause of Class A mishaps in aviation (Lonner et al., 2024) and can lead to catastrophic aviation mishaps. Although, Statistics show that only between 5 to 10% of all general aviation accidents are attributed to SD, 90% of those are fatal (FAA, 2024). SD occurs when a pilot's perception of direction, altitude, or position is incorrect due to conflicting sensory inputs, potentially leading to dangerous control errors.

Despite the availability of advanced instrumentation which can be used to help orient the pilot, the pilot's sensory confusion can lead to a lag in response, inappropriate response, and/or the inability to recover in time. For example, a well-known mishap leading to a loss of life occurred when an air force pilot was unable to effectively recover from SD, due to a combination of weather conditions, use of night vision goggles, and aircraft speed and attitude, leading to an inappropriate and unsafe ejection (O'Neil et al. 2017). This incident and many others highlight the severe consequences of SD, including the significant financial loss and the reduction of combat capabilities. SD remains a serious drain on USAF resources and personnel. During the ten-year period of 1990-1999, the USAF experienced 36 SD-related Class A mishaps costing a total of \$557M and the loss of 44 aircrew (Heinle & Ercoline, 2002).

In order to combat these issues, several solutions have been implemented. As aforementioned, advanced avionics and automation systems such as synthetic vision are incorporated into aircraft to assist pilots in maintaining situational awareness to manage SD (Glaab & Takallu, 2002). However, increasingly complex workloads can place pilots in situations where they find themselves relying primarily on sensory cues, leading them to question their aircraft displays and misjudge actual aircraft orientation (Lewkowicz et al., 2020). Additionally, pilots are taught to lean on crew resource management, using effective communication and teamwork among flight crew members to ensure that pilots can rely on each other to recognize and respond to SD collectively (Şenol & Acar, 2020). Yet there are instances where military pilots may be in a single seat aircraft or unable to get feedback from another pilot. Continuous training has been recognized as an effective method to help pilots accurately respond to SD (Pennings et al., 2020). However, implementing continuous training poses challenges, as it necessitates training methods that are: (a) resource-efficient, (b) rich in information and data, and most importantly, (c) engaging (Sitzman et al., 2018). Existing SD training methods typically fulfill only one of these requirements, making the realization of continuous training difficult. For instance, traditional classroom methods can be highly informative but fail to engage the learners, leading to decreased retention and effectiveness over time (Miller et al., 2013). Conversely, other methods might be engaging but demand substantial resources, making them impractical for continuous use. Additionally, students and instructors report that limited instructional time, inadequate examples of SD illusions, and insufficient student activities (especially through kinesthetic instruction) hinder the ability of current Naval aviation training on SD to provide optimal preparation of aviators to perform flight tasks (N172-117 stakeholders, personal communication, March 7, 2018). We propose a novel multi-method training approach that integrates immersive technology, specifically, virtual reality (VR), galvanic

vestibular stimulation, and an array of objective and subjective metrics, the training software tool will provide an array of SD illusion playback videos via VR. The tool aims to address transportability, engagement, and increased immersion while sustaining resource efficiency. Further, the ability to playback videos provides the trainee with the potential to review and analyze the SD experience and their performance during the training. The current work provides a review of the literature and the conceptual design of the SD training tool with the goal of building upon this work in future publications to provide information on the effectiveness of the approach. The following sections will begin by covering some of the more common SD training methods: classroom, vestibular rehabilitation therapy, controlled live training, and simulated trainers.

EXISTING TRAINING APPROACHES

Traditional Classroom Training

The traditional approach offers several notable benefits, primarily revolving around its structured and theoretical approach to imparting knowledge. It allows instructors to cover a wide range of topics systematically, ensuring that pilots gain a comprehensive understanding of SD and its various aspects. Classroom settings also facilitate interaction and discussion, enabling pilots to share experiences and learn from one another. This method is cost-effective compared to other training approaches, as it does not require expensive equipment or extensive resources. However, despite these advantages, classroom training can often lack the necessary engagement, which is critical for effective learning and retention. According to Lawson et al. (2017), this lack of engagement can result in lower retention rates and reduced application of the learned material in real-world scenarios, highlighting a significant drawback of this training method. One major issue is the inherent lack of practical, hands-on experience within the classroom environment. SD is a phenomenon best understood and managed through experiential learning (Stott, 2013). In a classroom setting, pilots are limited to theoretical knowledge, which might not fully prepare them for the real-time decision-making and physical sensations experienced during actual flight. Additionally, it is limited by the availability of instructors during a time where there is a difficulty finding enough instructors and pilots to fill the current open aviation roles (GAO, 2018). Classroom training can also suffer from a lack of individualized instruction. Classroom settings typically require instructors to address the needs of the entire group, which can make it difficult to cater to the specific learning styles and paces of individual pilots (Fake & Dabbagh, 2023). Some pilots may grasp the concepts quickly, while others may need more time and personalized attention. This one-size-fits-all approach can lead to inconsistencies in the learning outcomes, with some pilots not fully mastering the skills necessary to handle SD effectively. Finally, classroom training is often constrained by time limitations. The structured schedule of classroom sessions means that there is a finite amount of time available to cover a broad range of topics. This time constraint can result in a superficial treatment of complex subjects, leaving pilots with only a cursory understanding of critical concepts. Finally, the rigidity of classroom schedules might not align with the operational demands of pilots, making it challenging for them to attend all sessions consistently. This inflexibility can further impede the learning process and the overall effectiveness of the training.

Vestibular Rehabilitation Therapy

Vestibular Rehabilitation Therapy (VRT) Therapy intended to alleviate both the primary and secondary problems caused by vestibular disorders such as dizziness and balance. VRT involves specific exercises that result in gaze and gait stabilization such as head movement exercises, which help to compensate for imbalance and improve vestibular function (Han, 2021). One common type of VRT is sensory organization training, that helps improve the ability to use and integrate the information from the vestibular system, vision, and proprioception to maintain balance (Appiah-Kubi & Wright, 2019). This can involve exercises that challenge the patient to balance under various sensory conditions, such as on unstable surfaces or with eyes closed. A second type is the Barany chair that is used to train pilots and astronauts to handle disorientation and motion sickness by rotating the occupant, which helps diagnose balance disorders and evaluate vestibular function through induced eye movements and sensations of spinning. It is used in military and aviation contexts for training individuals to handle disorientation and motion sickness. The controlled spinning of the chair allows for effective adaptation and compensation in vestibular responses, improving balance and resilience to motion-induced disturbances. These approaches are useful; however, these options can lack the full range of conditions and sensations experienced in an actual flight scenario. For example, SD in flight involves not just vestibular (inner ear) cues which can be induced by the Barany chair but also visual and cognitive factors. It is important to provide both to prepare pilots.

Controlled Live Training

Controlled live training involves hands-on experience in the aircraft, where pilots experience SD while accompanied by a flight instructor. This training method allows pilots to develop their skills in a controlled yet realistic environment (Bles, 2008). This approach significantly enhances their ability to manage SD in real-world situations as they are training in their environment and truly experiencing what can take place. Additionally, the presence of an instructor pilot provides the pilot with additional guidance and feedback. However, this training approach has several challenges and limitations. First, the safety considerations, even with safety measures in place, the potential for an accident remains high due to the unpredictability of human's responses to SD (Poisson, 2014). In these exercises, trainees are expected to remain calm and the instructor will not be impacted by the illusion. However, flight environments are highly variable, and human responses vary greatly between individuals and even within the same individual under different conditions. Thus, while such training can be invaluable for preparing pilots for real-world scenarios, the inherent risks often make the use of flight simulators a preferred alternative. Additionally, flying is an incredibly expensive training method due to operational, fuel, and maintenance costs (Cao et al. 2024). These factors can limit the frequency and accessibility of controlled live training sessions, making it difficult to implement on a continuous basis, where continuous practice is important.

Simulated Trainers

Simulated trainers can offer pilots a more immersive experience through the integration of technology that provides a more realistic experience such as haptic feedback, VR, and movement. Simulators can be divided into two categories (i.e., low-fidelity and high-fidelity), although there are many aspects that can be included in each. High-fidelity simulated-trainers often offer a sophisticated and highly immersive training experience, closely replicating real-world flight conditions and scenarios (Havighurst et al. 2010). These simulators can provide pilots with a 360-degree experience, which is crucial for effective SD training. They allow for repeated practice without the risks associated with actual flight, making them a valuable tool for continuous training. However, high-fidelity simulators are expensive to acquire and maintain; requiring regular updates and changes to stay current with technological advancements and regulatory requirements, adding to their overall cost (Dwyer et al., 2015). Additionally, these simulators are often bulky and difficult to transport, limiting their use to specific locations. This lack of portability can hinder the widespread implementation of high-fidelity simulation training, especially in regions with limited access to such advanced equipment (Dwyer et al., 2015). Low-fidelity simulated trainers, while more affordable and accessible than their high-fidelity counterparts, present their own set of challenges. These trainers lack the immersive qualities of high-fidelity simulators, often failing to provide a comprehensive "360" experience necessary for effective SD training. As a result, pilots may not fully engage with the training, which can impact the effectiveness of skill acquisition and retention. The reduced level of realism in low-fidelity simulators can also lead to a gap between training and real-world application, potentially leaving pilots less prepared for actual SD scenarios. Despite their cost-effectiveness and ease of use, the limitations of low-fidelity simulated trainers highlight the need for a balanced approach that incorporates the immersive qualities of high-fidelity training while maintaining accessibility and affordability.

Induction of Spatial Disorientation

One approach to mitigating SD threats is to incorporate technologies to detect when a pilot is experiencing SD. Advanced technologies, such as wearable sensors, eye-tracking systems, and cockpit monitoring software, can provide real-time data on a pilot's physiological and cognitive state, enabling timely interventions to prevent disorientation-related incidents. These systems enhance situational awareness and decision-making by alerting pilots and ground control to potential disorientation, thereby increasing flight safety. However, challenges include: safe integration into the pilot-aircraft system in a way that won't interfere with normal flight and won't prevent safe egress under mishap conditions; potential data overload during periods of high intensity flight maneuvers; and ensuring that alerts are accurate and actionable without causing unnecessary distractions.

An alternative approach is to train pilots to recognize the onset of SD episodes, in combination with standard recovery procedures, to include deep reliance on instrumentation to the exclusion of visually or physiologically relayed information. Training pilots to recognize SD offers significant benefits and challenges. The primary benefit is enhanced flight safety; through training, pilots can better identify and respond to disorienting conditions, reducing the risk of accidents caused by misinterpretation of their aircraft's position. Since reproducing SD in an actual flight environment has significant risks, alternative approaches rely on simulators that replicate disorienting scenarios, helping pilots develop critical skills in transitioning from visual to instrument reliance. However, challenges with these capabilities include the high cost of maintaining them and the need to bring pilots to them, effectively removing

them from their operational duties. Combined with research that suggests SD training can decay relatively quickly if not reinforced regularly, there is a clear need for more accessible, easily maintained techniques.

Simulation and virtual reality (VR) have been integral to training pilots for SD since the mid-20th century, evolving from basic flight simulators to sophisticated VR systems that can aim to accurately replicate disorienting flight conditions (A. Petru and P. Frantis, "Using virtual reality for sensory illusion training," 2017 International Conference on Military Technologies (ICMT), Brno, Czech Republic, 2017, pp. 632-635, doi: 10.1109/MILTECHS.2017.7988834.). A core challenge with VR-only SD training approaches is their failure to provide the full range of conflicting sensory information, leaving out entirely vestibular inputs. As a result, the training provided by these tools does not fully align to the actual environment in which SD may emerge, opening the potential for adverse training transfer. To be effective, VR systems must include a means to stimulate both visual and vestibular illusions.

Galvanic Vestibular Stimulation

Galvanic Vestibular Stimulation (GVS) Integration is a non-invasive method of inducing SD, that involves the application of a small electric current to the vestibular system, specifically targeting the vestibular nerves, through electrodes placed on the skin behind the ears (Allred et al., 2024). This technique modulates the activity of the vestibular system, which is responsible for maintaining balance and spatial orientation. The electric current induces a controlled and predictable response in the vestibular organs, creating sensations of movement and balance disturbances without actual physical motion. GVS has been extensively used in research to study vestibular function and in clinical settings for vestibular rehabilitation. When GVS is applied, it generates an artificial stimulus that mimics the natural signals sent by the vestibular organs to the brain. This can lead to sensations of tilting, swaying, or rotation, depending on the parameters of the stimulation.

To better understand how GVS works we must first consider the underlying neurophysiology. The table below categorizes spatial disorientation into three columns (See Table 1). The first column lists common aviation illusions, such as the graveyard spiral, inversion illusion, and the leans. The second column specifies the organs mainly responsible for each illusion. Lastly, the third column explains how individuals misperceive the aircraft during these illusions, based on the three axes of aircraft stability: pitch, yaw, and roll. For instance, the false pitch angle illusion often occurs when a pilot experiences linear acceleration, causing the otolith organs to sense a backward force, leading to the perception of the aircraft pitching up. Such misperceptions can prompt pilots to make dangerous control inputs, like inadvertently pushing the stick forward during a false climb illusion, potentially resulting in a hazardous descent or crash. Therefore, the illusory perception provided in column 3 lists "pitch tilt". Additionally, information from table 1 indicates the application of GVS currents to address spatial disorientation illusions. For example, to simulate the false pitch sensation, a GVS current could be applied from the front to the back of the head. Conversely, to induce a "tilt backward" sensation, the current would be applied in the opposite direction. It is important to note that although GVS is not as risky as methods such as a live flight it can produce discomfort to the trainee such as skin irritation more commonly slight itching (Utz et al., 2011) and mild nausea (Quinn et al., 2015).

When examining common SD training methods, it is clear that each has its benefits and challenges, highlighting the need for a multi-method approach. A combination approach is needed to provide the learner with a comprehensive understanding of SD without compromising the immersive/physical experience that is needed to truly begin to prepare for SD illusions in the air. To achieve effective continuous training for SD, it is crucial to develop and integrate training methods that balance resource efficiency and learner engagement, ensuring that pilots can maintain high levels of proficiency in responding to SD throughout their careers. Additionally, the training method must provide pilots and instructors with a rich array of subjective and objective data to enhance their understanding and recognize triggers and patterns for SD. Providing the trainees with the ability to evaluate their performance and understand how it truly degrades can better prepare them to identify when SD may be taking place. Instructors provided with trainee data across differing approaches can use this data to improve their SD training approaches.

Table 1. Types of Spatial Disorientation

Common Illusions	Primary Responsible Organ Modalities	Illusory Perception
Graveyard Spiral	Semicircular Canals ¹	Yaw ³ Rotation
(Gillingham) Post-Roll	Semicircular Canals	Roll ⁴ Rotation
Coriolis Illusion	Semicircular Canals	Multi-axis Rotations
False Roll Angle	Otoliths ²	Roll Tilt
False Pitch Angle	Otoliths	Pitch ⁵ Tilt
Inversion Illusion	Otoliths	Upside-down Orientation
G-Excess Illusion	Otoliths	Overestimation of Tilts
The Leans	Semicircular Canals and Otoliths	Persistent Roll Tilt
Graveyard Spiral	Semicircular Canals and Otoliths	Level Flight

Notes. ¹ Semicircular canals: Located within the inner ear and are responsible for detecting angular acceleration of the head; ²Otoliths: Located within the inner ear and responsible for detecting linear acceleration of the head. ³Yaw: Movement of the aircraft along its vertical axis, causing side-to-side motion; ⁴Roll: Movement of the aircraft along its longitudinal axis, causing aircraft's banking motion. ⁵Pitch: Movement of the aircraft along its lateral axis, resulting in the aircraft's nose moving up and down.

MEASURING SPATIAL DISORIENTATION

The following section will outline physiological, self-report, and behavioral measures that can be layered onto training environments to assess and verify fluctuations of SD.

Physiological Measures Implementation

Physiological measures can offer exceptional temporal resolution and sensitivity while maintaining objectivity (Ficke et al., 2022). For instance, cardiovascular and electrodermal activity (EDA) measures can capture data second-by-second, enabling instructors to understand when participants experience fluctuations in SD. From this, physiological measures are highly sensitive to such subtle changes in SD over time. Physiological measures also provide greater objectivity compared to self-report surveys, where participants offer personal interpretations of their SD training experiences. In all, integrating physiological measures with behavioral and self-report data yields a comprehensive and reliable understanding of pilots' SD experiences throughout training. Instructors can gain insight into specific areas where participants encounter difficulties, facilitating a more personalized training experience. To provide a comprehensive overview of measures suitable for SD training environments, the following section will delineate recommended physiological metrics that have been previously used to assess SD.

EDA has been previously employed to measure visually induced sickness levels, a prevalent symptom in virtual SD trainers (Warwick-Evans, 1978; Chung et al. 2006). Positive correlations between EDA and sickness in flight and driving simulators have been found (Chung et al., 2006; Warwick-Evans, 1987). More specifically, higher maximum EDA changes and peak amplitude has proven to be an indicator of SD, as demonstrated in Tamura et al. (2018). Unlike cardiovascular measures, which can be influenced by both the parasympathetic and sympathetic nervous systems, EDA exclusively tracks sympathetic nervous system responses. By focusing solely on sympathetic activity, EDA provides a more direct measure of physiological arousal, free from the potential interference of parasympathetic activity (Marieb, 2003). As EDA measures offers minimal intrusiveness, additional equipment is needed for deployment. Additionally, analyzing EDA data can pose challenges due to the volume of information that needs processing. Such constraints should be considered when integrating EDA measures into SD training environments.

Cardiovascular measures provide a non-invasive approach for assessing heart rate and heart rate variability (HRV) using electrical leads (Johnson et al., 2021). During SD training, participants commonly encounter hazardous scenarios that trigger sympathetic system activation, resulting in an increase in heart rate and decrease in HRV (Bustamante-Sánchez & Clemente Suárez, 2020) It is important to note that heart rate is influenced by both the sympathetic and parasympathetic nervous systems, while the sympathetic system prompts elevated heart rate, the parasympathetic system leads to decreased heart rate (Taelman et al., 2009). Consequently, heart rate reflects a complex interplay between the sympathetic and parasympathetic systems, complicating the relationship between HRV and SD outcomes. Therefore, to strengthen the reliability of SD assessments, complementary physiological measures should be considered alongside cardiovascular measures.

Eye tracking metrics, such as gaze distribution, fixation frequency, and average fixation duration, provide valuable insights into pilot attention allocation (Ziv, 2016). Gaze distribution provides insights into where pilots look within the visual scene, such as their displays—indicated how attention is allocated across different areas of the visual view. (Kang et al. 2021). Whereas fixation frequency refers to the number of times a user remains still on a specific point of interest (Chung et al. 2003). Results from eye-tracking studies have found notable differences in scanning patterns and flight performance between pilots who've experienced SD compared to those who have not (Chung et al., 2003). Further, an increase in gaze distribution and fixation frequency on critical instruments correlated with lower levels of SD (Kang et al. 2021). As eye tracking measures have been used to objectively assess SD, additional physiological measures should be administered to strengthen the reliability of SD assessment. It is important to note that collecting eye tracking data can be strenuous and commonly requires additional equipment and software for data analysis, as eye tracking data produces high levels of noise.

Self-Report Measures

Self-report questionnaires including the subjective perceived stress questionnaire and the simulation sickness survey (SSQ) (Kennedy et al. 1993), have been used to assess the severity of SD (Erickson et al., 2023; Bustamante-Sanchez et al., 2020). The SSQ contains three subscales—nausea, oculomotor disturbance, and disorientation—all pertinent to assessing SD as it can elevate stress levels in individuals (Taelman et al., 2009). Previous work examining SD among helicopter and transport pilots found that after experiencing an SD event, pilots reported significantly higher stress measured via the stress perception questionnaire (Bustamante-Sanchez et al., 2020). Additionally, the SSQ has been applied to evaluate disorientation following vection illusions in VR (Erickson et al. (2023), with SD being successfully induced based on behavioral and performance-based metrics, which were supported by SSQ results. As self-report measures are widely available and validated, they are easily administered and analyzed. However, self-report surveys reflect the subjective interpretation of a trainee's SD experiences, leading to subjective responses. To enhance result reliability, it is essential to complement self-report findings with objective measures such as physiological assessments. Although self-report measures can be intrusive, particularly in real-world applications, where interruptions are challenging, they are essential for assessing dynamic changes in SD. In scenarios like aviation training, where pilot engagement is vital, administering surveys can disrupt performance. Therefore, scheduling self-report measures at the beginning and end of training sessions allows for less obtrusive assessments like behavioral or physiological measures to capture changes in SD effectively.

Behavioral Measures

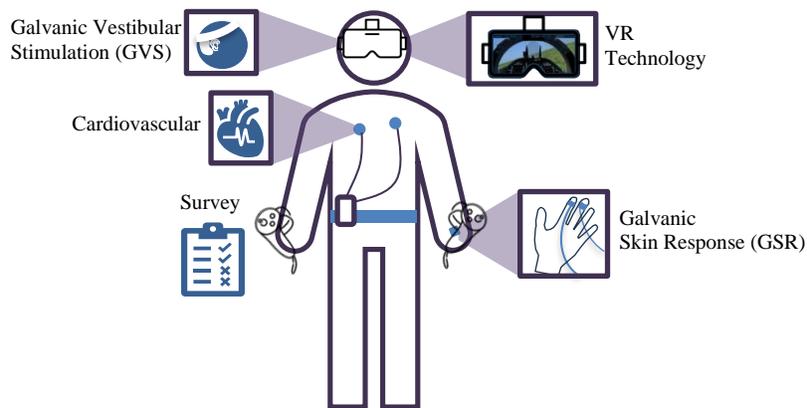
Behavioral measures can also be utilized to provide SD information. Although, they should be complemented by self-report and physiological assessments to fully understand SD. For example, aligning flight performance data with findings from physiological and self-report measures, can effectively confirm the successful induction of SD.

Behavioral data can be pulled in many ways, such as the use of physical aspects such as pressing a button for levels of disorientation that are being felt by the pilot has been previously used (Erickson et al., 2023). Reaction times can also be a useful tool to measure SD impacts, comparing the time it takes for a pilot to respond to visual, auditory, or tactile cues during disorientation scenarios can provide additional understanding for the trainee on severity of SD, such as measuring the delay in a pilot's reaction to correct an unintended roll or pitch during a simulated flight. Additionally, scan patterns and decision-making behaviors, such as relying on instruments vs. visual cues. Given their unobtrusive nature, behavioral measures can be seamlessly tracked without disrupting tasks or user engagement. It is important to recognize that individual differences in tolerance may influence behavioral responses and not solely reflect SD severity. However, when combined with physiological and self-report data showing consistent patterns, behavioral measures offer valuable insights into the fluctuation of SD over time.

As with the training approaches, the measures can and should be used in conjunction to provide rich information to both trainees and instructors. However, it can be difficult at times to understand results of these measures. For instance, interpreting physiological data can be a complex task given that most of this data is recorded on a second-by-second basis, leading to large volumes of data that need to be processed to remove artifacts and noise (Anwer et al., 2024). Additionally, despite the availability of software for collecting and analyzing physiological data, interpreting this data commonly necessitates the involvement of individuals with specialized expertise in physiological measures to ensure accurate interpretations. Further most physiological measures are not integrated into the training environments making it an additional cost to. Self-report measures are a useful tool as well but aren't as objective and can be impacted by the time and place the individual is taking their assessment. Further, behavioral data although useful, needs to be used in conjunction with other measures to more accurately understand whether SD is taking place. Further it is important to recognize that individual differences in tolerance of SD may influence behavioral responses and not solely reflect SD severity. By integrating data from various measures, including behavioral assessments, instructors can develop a comprehensive understanding of SD dynamics and its implications on performance. The goal should be to provide useful easily understood data that integrates as seamlessly as possible with the SD training approach.

A PROPOSED TRAINING APPROACH

We propose a novel multi-method training approach that integrates immersive technology, specifically, VR, GVS, and an array of objective and subjective metrics (see Figure 1). This comprehensive strategy aids in unraveling the complexities of SD development and severities within training settings by replicating the immersive experience of a real flight environment while also facilitating precise measurement of SD through the employment of multiple measures. The approach will utilize a training software tool that inputs available data from multiple resources to create a visual first-person playback in VR, of any mishap or incident, including editing existing SD illusions and creating their own notional mishaps. The VR output allows the user to have the perspective of the pilot and view the cockpit and outside world as well as the illusion from the pilot's viewpoint, while blocking out external environmental distractions. The addition of the GVS induces the SD for the user within the VR environment. Physiological tools are integrated into the training environment along with performance and self-report measures to not only obtain when spatial disorientation is being experienced but also the extent to the SD experienced. Additionally, both trainee and instructor would be able to see the fluctuations in SD, when the onset occurs, and their mitigation strategies. Given that SD is an elusive construct, employing triangulation from diverse metrics can enrich our comprehension of its development and escalation within training contexts. This approach could be particularly beneficial for pilot training and recurrent courses. The ability to playback the SD experience allows trainees the ability to learn from the experience and the instructor to utilize objective data in their review after the training takes place. The integration of SD questionnaires, the perceived stress and simulator sickness survey along with GVS will be utilized to verify the induction and levels of SD during the study. The proposed method offers an economical, low-footprint, and portable solution without compromising engagement or immersion, thereby beginning to address the limitations of existing SD training techniques. Our proposed approach can be leveraged in classroom SD training to enrich the training experience making it more engaging by allowing trainees to experience SD. Further, unlike many commercially available simulated trainers, our approach integrates GVS to ensure that the trainee is actually feeling the effects of spatial disorientation without the need to go through unrealistic movements used in Barany chairs, and verifying the extent of GVS using physiological and subjective metrics. Finally, the approach allows the user to experience an immersive and engaging SD event in a safe environment without putting themselves or an instructor at risk as opposed to live flight environments.

Figure 1. Proposed Approach Set Up

In our future work, we aim to test the multi-method software training tool to not only show the induction of SD but examine what data is most beneficial and how to present the data to instructors, thus overcoming issues related to the current presentation of physiological data. Pilot participants who have experienced SD will run through a VR SD illusion scenario using the training software tool. GVS will be used to ascertain the level of SD they experienced and correlated with physiological measures. Physiological data will be reviewed and correlated with previous studies examining SD in pilots. Participants will be asked to share their experience using the system and compare the training to the SD training they have done in the past to understand expectations, benefits, and drawbacks of the tool. A successful outcome of the novel training approach would be to provide momentum to revolutionize the current SD training for flight students without the need to enter a real aircraft. In turn, this proposed approach could provide cost effective recurrent training that is both safe and efficient in enhancing pilot's understanding of SD.

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