

THE USE OF TACTILE CUES TO MODIFY THE PERCEPTION OF SELF-MOTION

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ABSTRACT

An immersive technology being developed by the Army to provide enhanced situation awareness for military personnel involves the use of tactile stimulators arranged in a matrix pattern surrounding the torso. When activated sequentially the tactile display can be swept over the torso to provide a sense of motion. This tactile stimulus can alter the perceived experience of self-motion produced by large field-of-view displays. The tactile display can also alter the reflex responses to visual stimuli.

1. INTRODUCTION

Spatial disorientation (SD) and the subsequent loss of situation awareness (SA) account for a significant percentage of mishaps in aviation. The safety of the aircraft and the ability to perform the aircraft's mission is highly dependent on the pilot having an accurate awareness of the current situation, including the state of one's own aircraft, mission goals, external conditions, other aircraft, and other hostile factors. Without this SA, the pilot will be unable to effectively perform the mission. Although not restricted to the aviation environment, when loss of SA occurs in aviation, the consequences are more severe, frequently resulting in loss of life and or aircraft. Acquiring and maintaining SA becomes increasingly more difficult as the complexity and dynamics of the military aviation environment increase.

Situation awareness has been defined in the following manner, "The perception of the elements in the environment within a volume of space and time, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1988, 1995).

The first and critical step in acquiring and maintaining SA is to perceive the status, attributes, and dynamics of elements in the environment (SA Level 1, Endsley, 1995). Without an accurate percept of SA Level 1, the pilot will experience a loss of SA that can have severe and costly consequences. Spatial disorientation occurs when the pilot has an incorrect perception of the

attitude, altitude, or motion of one's own aircraft relative to the earth or other significant objects. This corresponds to an inaccurate perception of the elements in the current situation (SA Level 1).

Surveys spanning the past 40 years have shown that SD mishaps have a critical and often severe outcome. Based on accident rates for the United States (U.S.) Air Force, Navy, and Army, spatial disorientation mishaps result in the tragic loss of 40 lives on average per year (Gillingham, 1992; Durnford, Crowley et al., 1995; Braithwaite, Groh, and Alvarez, 1997). The cost of spatial disorientation mishaps also includes mission failure, the impairment of mission effectiveness, and the monetary value of aircraft and equipment loss. Considering the number of military air forces, commercial and general aviation, the estimated annual material cost of spatial disorientation mishaps is in the billions of dollars (Gillingham, 1992). Aviators need improved tools to recognize and/or prevent spatial disorientation.

Since 2001 the number of aviation mishaps attributed to degraded visual environment mishaps has increased dramatically due to increased operational tempo in desert environments. An illusion associated with brownout conditions isvection – the compelling sense of self motion in physically stationary observers. Visually inducedvection is frequently accompanied by behavioral and reflex responses including postural adjustments, motion/simulator sickness and optokinetic nystagmus. The latter is a visual reflex consisting of fast and slow phase eye movements to maintain focus on objects in the moving visual field.

In 1990, Rupert, Mateczun, and Guedry (1990) proposed that a tactile interface could be used as a "more natural" approach to convey position and motion perception during flight. Since tactile orientation cues present fast robust responses while posing minimal demands on cognitive reserve, the touch sensation is an ideal candidate to provide continuous, intuitive veridical orientation information.

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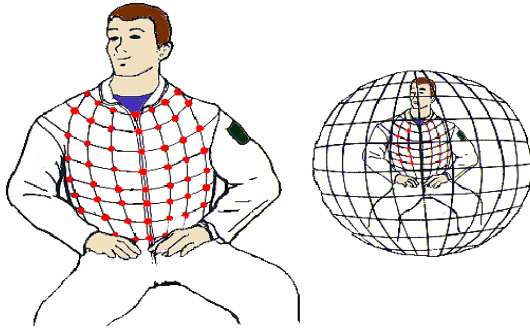


Fig. 1. Tactile Situation Awareness System (TSAS) concept

The Tactile Situational Awareness System (TSAS), developed initially by National Aeronautics and Space Administration (NASA) and the Naval Aerospace Medical Research Laboratory, and currently continuing development with the U.S. Army Aeromedical Research Laboratory (USAARL), was designed to improve situational awareness by presenting information to military personnel via the sensation of touch. The TSAS system consists of a controller and miniature tactile stimulators called “tactors.” The TSAS can obtain aircraft position, velocity, altitude, and threat information from the onboard aircraft data bus. Appropriate information, as dictated by the TSAS mode and processing algorithm, is then displayed to the pilot using the tactors. The tactors are embedded in an air-cooled cooling vest originally developed by DRDC Toronto. The above illustration (Fig. 1) indicates how the matrix of columns and rows of tactors can be arranged on the torso of the body. These tactors may be mapped to points in the external environment as indicated by the globe surrounding the subject in the above diagram.

The TSAS has been successfully demonstrated to present flight information in fixed and rotary wing aircraft (Griffin, Pera, Cabrera, and Moore, 2001; McGrath, 2000; Rupert, 2000). The TSAS has previously been evaluated for its robustness, intuitiveness, and effectiveness during general experimental tasks in the CV-22, MH-53M, and the MH-60K simulators, and in the T-34C, UH-60A (Fig. 2), and MH-53M aircraft.

Initial fixed-wing flight tests provided pilots intuitive non-visual information as to the direction “down.” The most difficult task for rotary wing pilots is hovering under visions of restricted visibility. Several algorithms were developed to provide velocity information for helicopter pilots. In the process of developing a velocity cue, the investigators experimented with providing flow information on the torso of the body.

The TSAS technologies have shown the potential to increase pilot SA and reduce pilot workload, especially

during complex flight conditions. Using TSAS, pilots demonstrated enhanced control of hover maneuvers, including transitions to and from forward flight in degraded visual conditions, relying on tactile cues for the necessary information. The awareness of aircraft movement over the ground or “drift” without looking at a visual instrument was the most important feature of TSAS (Cheung, Rupert et al., 2004; Jennings, Schultz et al., 2004).

The tactile display provided the opportunity to devote more time to other instruments and systems when flying in task saturated conditions. The TSAS permitted the pilot to concentrate on mission tasks, thereby reducing workload. These effects can substantially increase mission effectiveness.

The awareness of aircraft velocity over the ground or “drift” without looking at a visual instrument was the biggest advantage of TSAS. The maintenance of SA during reduced visual conditions was enhanced. The TSAS permitted the pilot to concentrate on mission tasks, thereby reducing cognitive stress. Overall, TSAS decreased pilot workload, enhanced SA, and increased the potential for survivability and lethality (McGrath 1998).



Fig. 2. USAARL UH-60 research aircraft

The current study examines whether tactile displays can reduce visual illusions encountered in the aerospace environment.

2. METHODS

2.1 Vection Stimulus

Self-motion perception was provoked in 12 healthy volunteers sitting motionless within the Visual Vestibular Sphere Device (VVSD) (Fig. 3 and Fig. 4). The VVSD is a 12 foot diameter sphere that can be rotated around a

subject seated upright with his/her head located in the center of sphere rotation.



Fig. 3 Visual Vestibular Sphere Device (VVSD) exterior view



Fig. 4. VVSD interior view during rotation

When rotated around the stationary subject, the random dot pattern which fills the subject's entire field-of-view provides a strong vection stimulus. Horizontal eye movements were monitored with electrooculography (EOG). The sphere rotation velocity was varied between 15 and 60 degrees per second.

2.2 Tactile Stimulus

The torso garment consisted of 8 columns with 5 pneumatic tactile stimulators (tactors) in each column. Tactor columns were located on the front, back, left and right sides and at 45 degrees between these cardinal headings. The rotating tactile stimulus consisted of two adjacent tactor columns being activated simultaneously and advanced clockwise or counterclockwise around the torso. Stimulus frequency was 40 Hz .

Following 45 seconds of visual vection stimulus at constant velocity, the tactile stimulus was applied for 30 seconds.

3. RESULTS

All subjects reported self-motion opposite to the direction of sphere motion within 15 seconds of onset of sphere rotation. There was no difference between clockwise and counterclockwise rotation. All subjects reported "saturated" vection – the rotating sphere appeared motionless with all motion perceived as self-motion.

When the tactile stimulus was applied all subjects experienced a change in velocity of the vection (self-motion) experience. All subjects noted a decrease in perceived velocity. Two subjects reported that the sphere appeared to stop momentarily and then continued to rotate at a slower velocity. Three subjects noted that the tactile stimulus was "jerky".

Optokinetic (OKN) eye movement data was available for 11 subjects. When the tactile flow stimulus was applied during constant sphere velocity, six subjects (55%) demonstrated a decrease in magnitude (intensity) of slow phase velocity or change in frequency of OKN as seen in the following eye movement recordings (Fig. 5 and Fig. 6). The changes in nystagmus were accompanied by a decrease in perceived velocity of rotation.

Five of the subjects who reported a decrease in vection velocity did not demonstrate a clear change in slow phase velocity or frequency on the OKN recordings.

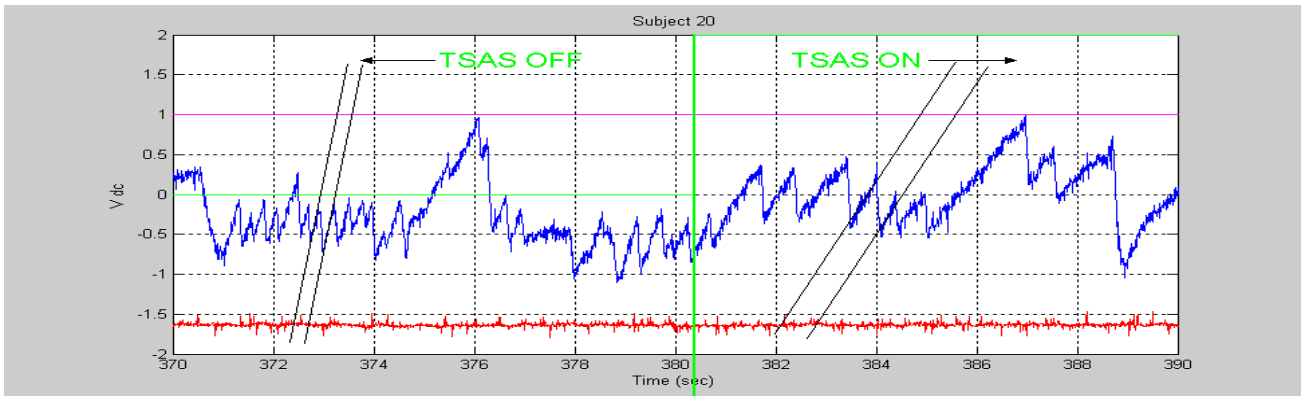


Fig. 5. Change in slow phase velocity following application of tactile flow stimulus. Slope of line indicates velocity of slow phase of OKN nystagmus. Shortly after the application of the tactile flow stimulus (vertical green bar) the slow phase velocity decreased.

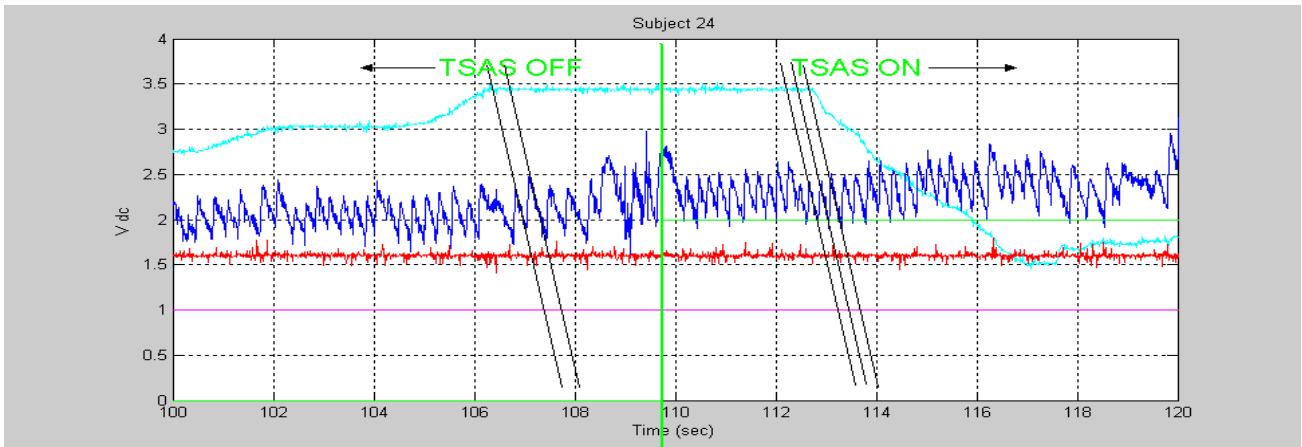


Fig. 6. Change in frequency of optokinetic nystagmus following application of tactile flow stimulus. Following application of the tactile flow stimulus (vertical green bar) this subject demonstrates an increased frequency of nystagmus.

4. DISCUSSION

For institutional review board reasons, all subjects in this experiment were informed prior to the experiment that the chair would not rotate. Despite full knowledge of the absence of motion, no subject could suppress the illusory sense of circular vection.

The experience of tactile “jerkiness” by three subjects relates to the stimulus area and density. In the current experiment the stimulus was applied to two columns at a time instead of several columns. When the density of the array is increased with additional columns there is also less tendency to experience the stimulus “jumping” from column to column in a saltatory fashion.

There has been considerable debate in the aviation industry as to whether motion based simulators provide better training than non-motion based simulators. Motion based simulators have many drawbacks in addition to significantly higher costs associated with the initial procurement and maintenance. The large footprint and non-portability prevents deployment of motion based simulators with troops to the war zone where simulators can best provide mission rehearsal capabilities. Small non-motion simulators are promoted for the capability of deployment but detractors claim that realism suffers from lack of motion cues.

The ability of tactile stimuli to alter or provide sensations of motion may promote the use of non-motion, portable simulators in-theater as mission rehearsal

devices. Considerable research needs to be carried out to determine the optimal hardware configurations as well as to develop software programs that provide compelling sensations.

There are several circumstances that produce vection illusions in the aerospace environment, often leading to mishaps. The issue of blowing sand or snow has led pilots to experience drift in the opposite direction of the blowing particles. There have been several mishaps where pilots have made control inputs to "correct" for the apparent motion with disastrous results.

In a debrief following the first moon landing by Neil Armstrong and Buzz Aldrin, the astronauts discussed the visual obscuration posed by the surface particulate matter driven across the surface of the moon from the force of the retro rockets as they approached the lunar surface, especially during the critical final 150 feet of descent. For the pilot on the left side, the movement of particles from right to left created a vection sensation of rightward movement. The normal response is to correct by application of a left control input. During the final 100 feet Buzz Aldrin frequently called "left drift" from instrumentation readings while Neil Armstrong did his best to correct. His comments concerning the last portion of descent were, "*I think I was probably over controlling a little bit in lateral. I was confused somewhat in that I couldn't really determine what my lateral velocities were due to the dust obscuration of the surface*" and "*I was surprised that I had as much trouble as I did in determining translational velocities. I don't think I did a very good job of flying the vehicle smoothly in that period of time. I felt I was a little bit erratic.*" (Jones, 1995). When the lunar lander touched down it was still drifting to the left but fortunately the velocity was not sufficient to turn over the lander module.

Illusions produced by vection can be countered or reduced as this set of pilot experiments demonstrate. When pilots or astronauts have the availability of tactile velocity cueing, the opportunity exists to prevent mishaps associated with vection illusions in the aviation and space environments. Tactile technologies being developed by the Army will be available when astronauts return to the lunar surface.

Motion sickness, including simulator sickness, is influenced by many factors other than physical motion. The ameliorative effects of accurate visual stimuli on sea sickness are well known and used by seasick-prone individuals when they leave the hold to stand on deck where they can view the horizon. It is postulated that veridical visual motion is integrated with other sensory information to reduce the effects of the motion stimulus. While preparing the TSAS for the UH-60 hover demonstration, several tactile algorithms were developed

to provide a sense of vertical flow or motion for the helicopter pilot. One such algorithm sequentially activated the eight rows in a torso display which provided a sense of moving up or down depending on the direction of row activation. Using touch, in a similar manner as vision is used to provide veridical motion sensations; it may be possible to offset the effects of nauseogenic motion stimuli through application of tactile flow cues.

Further research using more accurate eye movement recording devices is needed to understand the basis of inter-subject differences. The source of individual differences in perception is often difficult to examine experimentally since there are so many factors involved, one of which is the influence of past experience including training. In this experiment, which was essentially a pilot series to determine whether tactile flow stimuli could alter visual illusions, there was not an opportunity to examine the role of training. It is anticipated that one or more training sessions for subjects to correlate the tactile with visual and motion experiences will result in more uniform reflex responses. This is a critical area for future studies and may explain the variation in eye movement recordings between individuals.

5. CONCLUSIONS

This experiment demonstrates that tactile stimuli can influence both the perceptual and reflex processes involved in the visual-vestibular-somatosensory integration responsible for self-motion perception in space. The opportunity to enhance the level of immersion for personnel using simulators is only one facet of tactile technology. The proprioceptive system is comprised of the skin-muscle-joint and vestibular systems. Depending on the degree to which the tactile cues can influence vection, it may be possible to substitute tactile proprioceptive motion cues in lieu of vestibular cues provided through the motion-base currently used in high fidelity simulators. By eliminating the need for motion, simulators can become significantly cheaper and more portable for personnel who are in need of mission simulators close to the site of deployment. Since tactile cues can change motion perceptions, it may be possible to effect a reduction in simulator sickness for both motion and non-motion based simulators. Tactile stimuli can provide motion and position cues to operators of unmanned systems as well as enhancing the situation awareness of personnel in vehicles which provide restricted or no visual reference to the outside environment.

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