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Evaluation of Tactile Cueing for Maintenance of Hover Position and Altitude

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14. ABSTRACT

The U.S. Army Aeromedical Research Laboratory (USAARL) evaluated the utility of the tactile cueing situational awareness system (TSAS) for maintaining hover position and altitude in the UH-60 flight simulator. The results did not support efficacy, and the authors suggest that the short duration (30 minutes) of training was insufficient for participants to effectively learn the TSAS.

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Background

The tactile situation awareness system (TSAS) was developed to provide information via the under-utilized sense of touch (Rupert, Guedry, & Reschke, 1993; McGrath, Estrada, Braithwaite, Raj, & Rupert, 2004; McGrath, Suri, Carff, Raj, & Rupert, 1998). Providing tactile information allows the pilot to maintain orientation while looking away from the aircraft instrument panel. The full TSAS array consists of a custom fit, upper-body torso suit, shoulder straps, and a seat. All three components contain tactile stimulators (tactors) that respond to hardware and software in the aircraft and provide information to the pilot on the aircraft's altitude, drift direction, and magnitude.

One major disadvantage of the full TSAS array is the impracticality of its implementation in military settings. Specifically, the system is bulky, expensive, and difficult to maintain, and therefore not a realistic option in the harsh field environments in which Army Aviation operates. While research flights for the TSAS conducted in a UH-60 helicopter resulted in improved aircraft control, increased pilot situational awareness, and reduced pilot workload (McGrath, et al., 2004; Raj, Suri, Braithwaite, & Rupert, 1998), the expense of fitting each pilot with a custom TSAS vest remains a challenge.

Given the potential of the TSAS, efforts were made to construct and develop a more practical Army system. Thus, TSAS-Lite, which consists of eight tactors placed every 45 degrees around the waist in a belt, was developed. Curry, Estrada, Webb, and Erickson (2008) examined whether this modified system would prove as effective as the full TSAS array in providing helicopter drift information to the pilot. The results showed that the limited-display provided increased aircraft control and safety during low speed maneuvers near the ground in degraded visual conditions. Even in fatigued pilots, following 31 hours of sleep deprivation, the TSAS-Lite display augmented traditional aircraft instruments in an intuitive, non-visual manner, particularly with a hovering task. These results showed that the addition of TSAS-Lite significantly improves pilots' ability to control drift during take-off and reduces drift error during hover. In fatigued pilots, all measures of performance related to drift were improved with use of the belt compared to performance without the belt. Overall, the results indicated that the belt significantly improved pilot perception of drift and situation awareness, and reduced mental stress. Additional studies using the TSAS have shown it effectiveness to aid pilots in maintaining a hover position during a simulated rescue hoist task (e.g., Kelley et al., 2013).

To further evaluate the effectiveness of TSAS-Lite during varied maneuvers and under a range of conditions, the present study examined the efficacy of the TSAS-Lite belt specifically for maintaining a 60-second hover over a ship at a specified position and altitude following a 30-minute training session. We hypothesized pilots would be more efficient at maintaining their position and altitude when equipped versus not equipped with the TSAS-Lite belt.

Methods

Prior to execution, the study received Institutional Review Board approval.

Participants

Fifteen rated UH-60 Blackhawk aviators with a minimum of 250 flight hours participated in the study. All participants were male with an average age of 36.6 and 1867.7 flight hours. All participants were recruited from Fort Rucker, AL. The study was conducted at the U.S. Army Aeromedical Research Laboratory (USAARL) and utilized the laboratory's UH-60 flight simulator.

Materials

Flight Simulator.

The UH-60 research flight simulator consists of a simulator compartment containing a cockpit, instructor/operator station, an observer station, and a 6-degree-of-freedom motion system (figure 1). It was equipped with six Dell precision 450 personal computer visual image generator systems that simulate natural helicopter environment surroundings for around-the-clock ambient light conditions. The research data acquisition system consisted of a laptop computer that samples and stores up to 30 flight parameter variables. The key flight parameter dependent variable in this study was range (ft) of "helicopter" from target.

Figure 1. USAARL UH-60 flight simulator.

Tactile system.

The early experiments involving tactile cueing using pager motors were not successful in the aviation environment due to ambient noise and vibration obscuring the tactile stimulus (for a discussion, see McGrath, 1999). For the past 10 years, the electromechanical tactors used for TSAS experiments manufactured by Engineering Acoustics, Inc. have proven sufficiently robust to provide tactile cueing in the noisy helicopter environment. Recent technology developments in piezoelectric materials allow for much lighter, less obtrusive, variable frequency, tactile stimulators thus providing more opportunities for tactile information to augment current environments.

The TSAS-Lite belt consists of a customized eight channel tactor driver board and eight electromechanical tactors (Engineering Acoustics, Inc.). The belt is made of a flexible neoprene with VelcroTM fastenings (figure 2). The aircraft seat also contains six tactors and two in the shoulder harness (one left, one right) to provide altitude information. The central processing unit and tactor drive electronics are protected in a water-resistant-sealed-housing with data, tactor, and operator switch interfaces. The system stimulates the tactile sense to relay to pilots information regarding spatial orientation and situational awareness. Specifically, the tactors provide a vibrating stimulus at 90 Hz ± 20 percent with three rates of firing depending on preset flight conditions. The sensation provided to the pilot by the tactors is similar to the vibration of a standard electric toothbrush. Altitude, position, velocity, and vector information is transmitted from the UH-60 flight simulator to the tactile system. This information is displayed via the electromagnetic tactors located on the belt. During flight maneuvering, the location of the tactor on the belt-line is used to indicate the direction of the target's motion (drift) relative to the pilot's position. This information determines whether and which tactor produces a stimulus and at what intensity. For example, when the helicopter (simulator) drifts to the left, the corresponding left position tactor vibrates to alert the pilot of the drift so that he/she can compensate by moving the helicopter to the right.

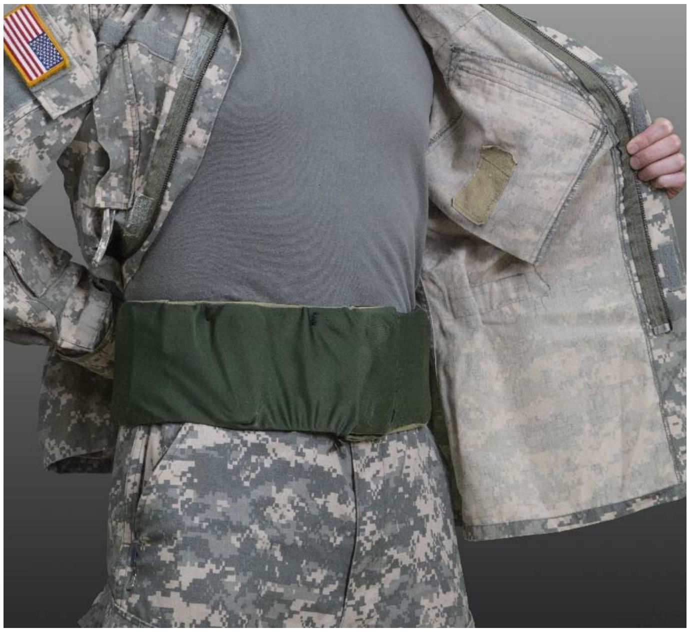

Figure 2. TSAS-Lite belt worn by aviator.

Figure 3. Inside view of the TSAS-Lite belt.

Procedure

All participants were rated UH-60 Blackhawk aviators with a minimum of 250 flight hours. After eligibility was assessed, participants provided written consent to participate in the study and then completed the demographics questionnaire. All participants were then provided with 30 minutes of tactile cueing training in the USAARL UH-60 Flight Simulator in which they were trained on drift cues, high and low altitude cues, navigation cues, and banking/pitch cues. Participants then completed a pair of 30-minute flights; flights were randomized and counterbalanced between subjects for receiving tactile cueing on either the first or the second flight. The flight path consisted of a one-minute hover at the beginning and end of the flight, as well as piloting over a body of water with oil platforms located throughout and low visibility. The first leg participants took off from the dock and landed on the ship, while the second leg participants took off from the ship and returned to the dock. Participants completed two brief questionnaires to ensure no simulator sickness symptoms presented. Participants were then compensated for the study and released.

Statistical Analysis

Raw data were converted to differences from the hover start value. The absolute values of these differences were used for all further data inspection and analyses. Data were inspected for outliers prior to analyses and all values above and below two standard deviations from the mean were removed from the analyses. Descriptives and normality tests were calculated and conducted to inspect the data prior to analyses. Data were then aggregated by subject to produce means (or medians if non-normal) and maximum values of the outcome measures (difference of latitude position from hover start, difference in longitude position from the hover start, difference in altitude above ground level [AGL] from hover start, and difference in altitude mean sea level [MSL] from hover start). Eight paired-samples *t*-tests were run to compare the aggregated mean (or median if non-normal) and maximum values of the four outcome measures when equipped versus not equipped with TSAS.

Results

Inspection of the data showed incorrect recording of altitude measures for one test run and was thus removed from any further analyses. This resulted in one participant having only one test run's worth of altitude data for analysis in the TSAS-on condition whereas all other participants had data from two test runs.

Descriptives and Normality Tests

Descriptive statistics were calculated for each of the four outcome measures including mean, standard deviation, median, skewness, and kurtosis. Additionally, a test of normality was calculated for each (Kolmogorov-Smirnoff test). All measures were not normally distributed; latitude, $D(144{,}879) = 0.353$, $p < .01$; longitude, $D(147{,}185) = 0.394$, $p < 0.01$; AGL, $D(142{,}021) = 0.107$, $p < 0.01$; and MSL, $D(141{,}709) = 0.109$, $p < 0.01$.

Table 1. Descriptive statistics for all outcome measures (differences from hover start point)

Outcome Measure	*N*	*Mean*	*SD*	*Median*	*Normal*
Latitude	144,879	0.0000983986	0.0002607356	0.000045	No
Longitude	147,185	0.000128106	0.0004777482	0.000051	No
AGL	142,021	11.1481	8.9529	9.2589	Yes
MSL	141,709	11.3525	9.2007	9.4623	Yes

Median Comparisons

Given that all outcome measures violated he assumption of normality, mean median values (in addition to maximum values) were used in the comparison analyses. No comparisons were significant.

Table 2. Comparison of the mean, median, and maximum values of all outcome measures between TSAS-On and TSAS-Off conditions

	TSAS-On		**TSAS-Off**		***t***	***df***	***p***
Outcome Measure	*Mean*	*SD*	*Mean*	*SD*			
Median Latitude	0.00004	0.00001	0.00005	0.00002	1.3830	9	0.200
Maximum Latitude	0.00090	0.00152	0.00032	0.00043	-1.0770	9	0.310
Median Longitude	0.00006	0.00002	0.00006	0.00005	0.712	9	0.495
Maximum Longitude	0.00190	0.0035	0.00026	0.00016	-1.4140	9	0.191
Median AGL	11.3188	6.0677	8.9568	2.8097	-1.146	9	0.281
Maximum AGL	31.7860	11.0616	26.6877	11.0616	-0.8000	9	0.444
Median MSL	12.5641	9.3681	9.7419	3.1314	-0.887	9	0.398
Maximum MSL	29.5201	11.7115	28.0047	11.2611	-0.2900	9	0.779

Discussion

The objective of this study was to evaluate the efficacy of TSAS-Lite on pilots' ability to maintain position and altitude in a hover. Participants in the study received 30-minutes of training on the TSAS-Lite system prior to completion of the hover task in a simulator. The results of the study did not find any evidence to reject the null hypothesis which is inconsistent with past research on the efficacy of TSAS-Lite on maintaining a hover position (Kelley, et al., 2013). In past studies, however, training sessions have exceeded two hours and in this study training duration was 30 minutes. This short duration may be insufficient to learn the TSAS-Lite system and thus yielded the present results. In future studies, we recommend longer training durations and evaluation to determine the optimal duration and number of sessions for maximum impact on pilot performance.

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