Effect of Tactile Feedback on Unmanned Aerial Vehicle Landings

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ABSTRACT

The U.S. military has developed and employed unmanned aerial vehicles (UAVs) in various operations since the late 1990s. Feedback from the UAV operating station is vital for the pilot to control the UAV. The current predator UAV control setup has a monitor that shows the pilot a map and another monitor that displays a nose camera view combined with a heads-up display (HUD). Since operators control the UAV from a ground control station that is remote from the actual aircraft, the pilot is not provided with the normal auditory, vestibular, and proprioceptive feedback they would receive in the actual aircraft. Because of the remote operation of the UAV, they are also not immune to mishaps. In fact, the landing task alone contributes up to 22% of all UAV mishaps. The purpose of this study is to assess the potential for a vibrotactile vest to provide tactile feedback to UAV pilots while landing. This study used two groups of participants. The first group used the UAV simulator as it is currently employed with no tactile vest. The second group used the UAV simulator while also using the tactile vest. We examined the learning performance of each group by measuring the number of trials it takes to obtain a passing landing score for the initial condition each participant is assigned. After obtaining a passing score, the participant switched to the other condition (vest or no vest) and completed an additional three trials. We then used the root mean square (RMS) error from an optimal flight path to analyze the impact of initial training with and without the tactile vest. This study included 30 participants with 15 participants assigned to each group. Participants were drawn from United States Air Force Academy cadets in an upper-division leadership class. All tests were performed on a UAV synthetic task environment (STE) simulator located in the Behavioral Sciences and Leadership Laboratory. The findings showed that the vibrotactile vest can help UAV pilots more accurately perform a landing.

ABOUT THE AUTHORS

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2Lt Donald T. Aretz recently graduated from USAFA with a major in Human Factors. During his time at USAFA he led several research projects and was named the department's top cadet in the human factors major. 2Lt Aretz will be attending undergraduate pilot training at Laughlin AFB Texas following a short assignment at Shaw AFB South Carolina.

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INTRODUCTION

As the Air Force moves toward the future there will be a greater utilization of unmanned aerial vehicles (UAVs) to support the full spectrum of missions. Pilots of UAVs are faced with a difficult task of controlling the aircraft from a remote ground control station. Feedback from the UAV operating station is vital for pilots to effectively control the UAV. The current UAV ground control station includes a monitor that shows the pilot a map and another monitor that displays a nose camera view combined with a heads-up display (HUD). Since operators control the UAV from a ground control station that is remote from the actual aircraft, the pilot is not provided with the normal auditory, vestibular, and proprioceptive feedback they would receive in the actual aircraft. The “out of cockpit” experience while piloting UAVs potentially contributes to a larger mishap occurrence rate than manned aircraft. UAVs have on average 141 mishaps per 100,000 flight hours, while manned aircraft have one mishap per 100,000 flight hours. 22% of these mishaps occur during the landing phase of UAV operation (Tvaryanas, Thompson, & Constable, 2005). Tactile feedback may be a method to reduce the demand on a UAV pilot’s visual load and provide the kind of feedback needed to effectively operate the UAV in all phases of its mission.

This study investigates the potential training advantages of a vibrotactile vest that is used to give the pilot tactile cues concerning the altitude in relation to an optimal landing pattern. The focus of our study is on the Predator UAV since it requires stick and throttle control, especially during the takeoff and landing phases. In particular, this study used the UAV synthetic task environment (STE) simulator provided by the Air Force Research Laboratory (Mesa, Arizona). The UAV STE is similar to the actual trainer used by Predator RQ-1A pilots. In addition to the two monitors for the map and nose camera view, the UAV also includes a hands-on-throttle-and-stick (HOTAS) for control input. Other UAV control stations, like the one for the Global Hawk, do not utilize a HOTAS system. Instead, the flying is fully automated and the Global Hawk operator primarily enters commands though a keyboard. Since the Predator has a HOTAS system, it is important to develop a control system that allows the UAV pilot to control the UAV with the appropriate level of feedback.

Tactile feedback is a relatively new field of research and its potential applications have not yet fully been identified. Tactile feedback may be a great asset to many areas requiring users to divide their attention among different tasks. One model that helps to explain how users divide their attention is the multiple resource theory (MRT). The MRT states that there are multiple “pools” of cognitive resources, and if one of these resource pools is being completely used during a task, then no more information of the same resource will be processed (Wickens, 1980, 1984, 1991). Examples of these resources are audio and visual stimuli. In a given task, if the operator primarily processes visual information from displays, they will most likely be overloaded when more visual tasks are added. To prevent the user from being overwhelmed, one would channel part of the information through auditory means. The MRT can also apply to tactile feedback since it is a sensory system. Tactile feedback is not currently used in UAV ground control systems and provides an untapped pool of resources to display information to the pilot. If information can be channeled through tactile means, then the information overload to UAV pilots may be reduced.

Terrence, Brill, and Gilson (2005) measured the time it took for participants to indicate a perceived direction using auditory cues and tactile cues. The study used five body orientations (supine, kneeling, sitting, standing, and prone) and a 45 degree separation between directions being tested. The results from the study showed the tactile responses to be significantly faster than auditory responses. Absolute angle differences between perceived and presented cues were significantly smaller with the tactile feedback. If tactile feedback is faster and more accurate in stimuli detection, then UAVs would have much to gain by moving some of the control feedback into the tactile area.

Calhoun, Draper, Ruff, and Fontejon (2002) compared the performance of tactile feedback and visual feedback in a study using the UAV STE at Wright-Patterson AFB. The study had participants detect and identify system faults while completing a tracking task. The study found that the responses with tactile feedback were significantly faster than the visual response times. Another study by Calhoun, Draper, Fontejon, Guilfoos, and Ruff (2004) had participants respond to critical events while performing multiple tasks on a UAV STE. The critical events were alerted with aural or tactile cues. The study found no significant difference between aural and tactile cues, and may imply that portions of auditory cues used on UAV control stations can be moved to tactile cues with no performance loss, thus reducing the demand on auditory resources.

Another study performed by Cheung, Craig, Jennings, Rupert, and Schultz (2004) utilized a tactile situational awareness system (TSAS) to see whether tactors can help helicopter pilots in poor visual conditions. The study measured lateral (fore/aft) inputs from the pilots during good and poor visual conditions. There were two scenarios, one with TSAS off and another with TSAS on. Helicopter pilots landed on a simulated frigate at night with poor visual conditions. The study concluded that TSAS improves pilot performance in all areas.

van Erp, Veltman, and van Veen (2003) completed a study using tactile feedback on helicopter pilots and altitude monitoring. The study had helicopter pilots wear a tactile system on their torso, shoulders, and thighs. Two scenarios were presented to the pilots. One scenario was just a presentation of a direction and desired altitude. The second added current motion direction. A cognitive task was completed by each pilot during half of each scenario. The measured variables were the absolute altitude error and root mean altitude error. The results of the study showed that the tactile feedback reduced altitude error by half and also did not affect the mental effort rating. The tactile effect was the same in each scenario.

The question this study is investigating is whether the application of tactile feedback to a UAV ground contol station will help UAV pilots control the UAV better, leading to fewer mishaps. Our first hypothesis is that there will be a difference in the number of trials for a successful landing between participants utilizing the tactile vest and those not using the tactile vest, with those exposed to the tactile vest first performing better. The second hypothesis is that there will be a difference in the average root mean square (RMS) error on the post-trials. After switching roles (post-trials) we predict that the group who initially did not wear the vest will have a lower RMS error on landing than the group who initially did wear the vest and then took it off for the post-trial comparison. Our prediction for the second hypothesis is based on the fact that taking off the vest for post-trial conditions will create more of a learning conflict for the vest group because of their dependence on the vest in the initial conditions.

If the tactile vest does show to help performance for UAV pilots it may help reduce the number of UAV mishaps. Reducing the number of UAV mishaps will help save the Air Force money and improve mission effectiveness.

METHOD

Participants

The participants in this study consisted of 30 cadets at the United States Air Force Academy (USAFA) who were enrolled in the Foundations for Leadership and Character class. All participants were between the ages of 19 – 23 (29 males, 1 female). Participation was voluntary and participants received extra credit in their course. Participants came from the upper three classes (sophomores, juniors, and seniors). All participants had completed the soaring program at USAFA to ensure we had a relatively homogeneous level of flight experience.

Materials

Equipment consisted of a Dell 2.0 GHz, Pentium 4 processor with two 17" monitors. Software used was the UAV STE provided by the Air Force Research Laboratory (see Figure 1). The vibrotactile vest is made by TNO (Netherlands Organisation for Applied Scientific Research), a research company from Holland. The vest contains 64 tactors that can be programmed to give specific low-frequency vibration feedback. Figure 2 shows the TNO vibrotactile vest as implemented with the UAV STE. Nine of the 64 tactors were used in this study.

Figure 1. UAV STE with hands-on throttle and stick (no vest condition).

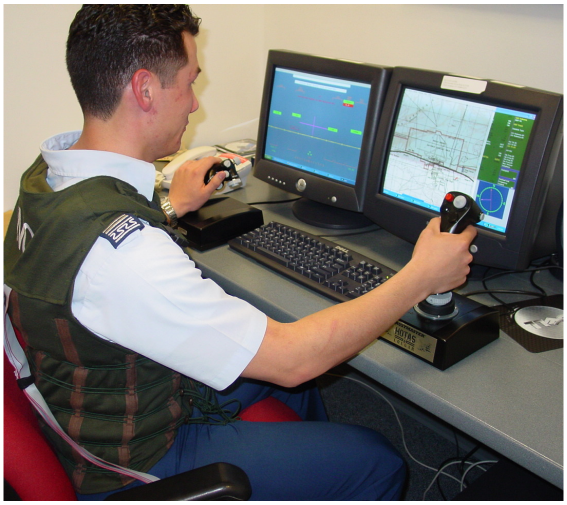

Figure 2. TNO vibrotactile vest as implemented with the UAV STE in the vest condition.

Design and Procedure

Participants read and signed the informed consent document and received information on the study before beginning. Participants had to pass a basic maneuvering task to a specific altitude and airspeed criteria. Specifically, participants learned how to: read the instrument displays on the monitor, feel how the tactile vest gives feedback, control the aircraft, and perform basic maneuvering tasks. Once the participant passed all criteria of the basic maneuvering task, they then performed the primary experimental task of landing the UAV.

The primary experimental task involved the participant completing a landing task on the UAV STE. The landing task started the participant downwind from an airfield. The participant controlled the UAV from the downwind position until the UAV had landed. During this portion of the study two different groups of participants were used. The first group flew the UAV using a tactile vest, and landed the UAV using information from both the UAV STE display and tactile vest. The second group flew the UAV without the tactile vest, and used only the display on the UAV STE to land. Software in the UAV STE monitored the UAV's altitude and when the participant flew the UAV outside the specified altitudes. The UAV STE software communicated with the tactile vest software during the entire landing task and alerted the participant when they were outside specific altitude parameters (i.e., status information). Figure 3 shows a notional picture of how the vibrotactile vest was configured to provide altitude deviation cues to the participant. When the participant was within +/- 10 feet of the desired glideslope, the vibrotactile vest was silent. If the participant was greater than 10 but less than 20 feet above or below the desired glideslope, the middle row of tactors vibrated "softly" (100 milliseconds on, 600 milliseconds off). When the participant was greater than 20 feet above or below the desired glideslope, the top row of tactors vibrated at greater intensity and frequency (200 milliseconds on, 100 milliseconds off). Both groups flew the landing task until they achieved a passing score. The passing score was an RMS error of 20 feet or less. The independent variable was the presence of the tactile vest during the completion of the landing task. The dependant variable was the number of trials it took each participant to achieve a passing score on the landing task, which was measured by the UAV STE software.

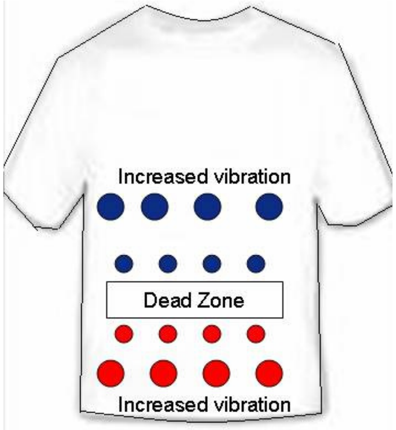

Figure 3. Arrangement of tactors on vibrotactile vest to provide altitude deviation feedback.

The final part of the experiment involved the participants completing the same landing task as in the primary experiment; however, each group switched roles. The group that did not wear the tactile vest put on the vest to complete three final landing trials. The group that wore the tactile vest completed the three post-trial landings without the vest. The RMS error from the optimal flight path was used on these three post-trials to determine the impact of initial training with and without the tactile vest.

RESULTS

A one-way analysis of variance (ANOVA) was run on the data to determine the impact of wearing the tactile vest on the landing task. Table 1 shows the mean and standard deviation (SD) by condition for each of the dependant variables. The ANOVA showed a significant difference for the number of trials needed to complete the landing task for the vest and no vest conditions, $F(1,28) = 20.70$, $p < .0001$. There was also a significant difference in the glideslope RMS error between the two conditions, $F(1,28) = 5.34$, $p=.028$. The glideslope RMS error for the post-trial conditions was not significant, $F(1,28) = 1.871$, $p=.182$. The results are graphically shown in Figures 4 and 5.

Table 1. Overall performance results of participants by condition.

		Vest	**No Vest**
# of Trials	*Mean*	3.53	7.13
	SD	1.41	2.72
Glideslope RMS Error	*Mean*	38.57	54.53
	SD	12.18	23.82
Post-trial Glideslope RMS Error	*Mean*	31.04	25.82
	SD	10.40	10.49

We also tested the effect of condition order for both groups. Figure 6 shows the glideslope RMS error for each condition (vest vs. no-vest) and trials (initial trials and post-trials). A significant interaction was found between the pre- and post-trial glideslope RMS error, $F(1,28) = 7.503$, $p=.011$, indicating a differential effect for the two groups. Overall, both groups experienced a significant decrease in glideslope RMS error from the initial trials to the post-trials, $F(1,28) = 21.973$, $p<.0001$. However, the no-vest group experienced a more significant decrease in glideslope RMS error when they put the vest on after the initial trials ($p=.001$). Although the vest group did experience a decrease in glideslope RMS error when taking off the vest for the post trials, it was much less significant ($p=.096$).

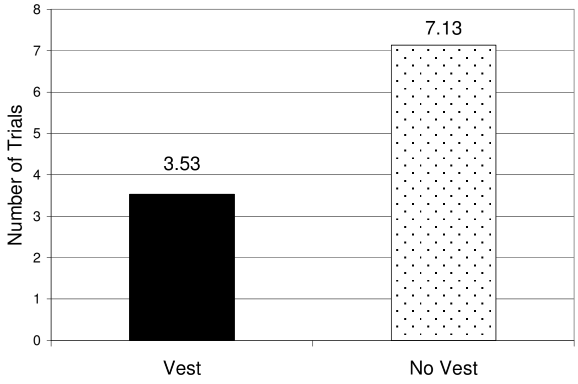

Figure 4. Comparison of mean number of trials until correct glideslope achieved.

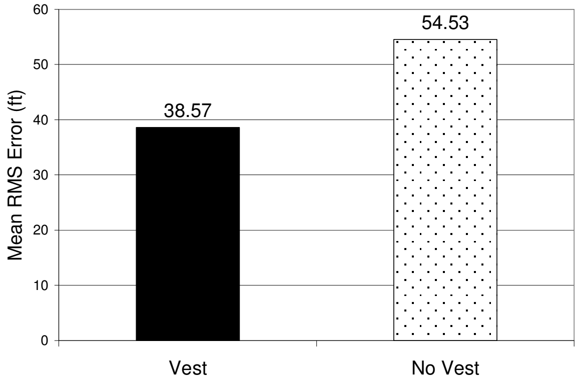

Figure 5. Comparison of mean glideslope RMS error for initial trials.

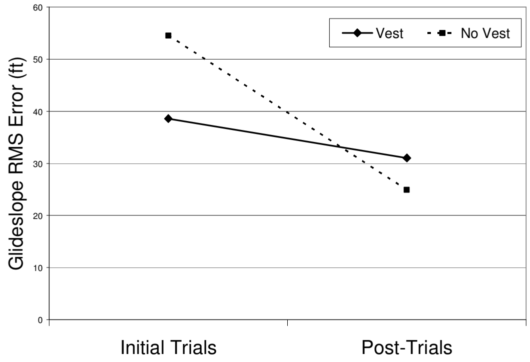

Figure 6. Comparison of glideslope RMS error for initial and post-trials by vest condition.

DISCUSSION

The data collected in this study supported the primary hypothesis; trials until a passing score using the vest were significantly fewer than not using the vest. In addition, the participants in the vest condition had a significantly lower glideslope RMS error on the initial trials. The secondary hypothesis was also supported showing that the glideslope RMS error for the participants who switched to the vest decreased more significantly than the participants who initially wore the vest and then had to perform three trials without the vest.

The performance of the vest condition significantly outperformed that of the no-vest condition in number of trials until the landing task was successfully completed. The performance of the vest condition supports the possibility that tactile feedback can be used in training novice pilots to fly UAVs.

Both groups were essentially at the same level of performance on glideslope RMS error during the post-trials where they had to fly three landing tasks in an opposite condition. This is evident in the non-significant result for post-trial glideslope RMS error when comparing the two groups (mean RMS error of 31.04 for vest group and 25.82 for no-vest group).

Even though both groups were at roughly the same performance level during the post-trial conditions, this result showed a different performance improvement for the two groups. The vest group had probably experienced most of their learning while initially wearing the vest whereas the no-vest group was still learning during the initial trials without the vest. Switching to the vest significantly added to their learning performance and dramatically decreased their glideslope RMS error. The significant decrease from initial trials to post-trials in the no-vest condition supports the notion that a tactile vest could potentially improve UAV pilot performance, even if they have learned certain tasks without tactile feedback. For the group that had to switch from the vest to no-vest trials, enough learning remained with them to show that the vest had made an impact on the overall training time (e.g., number of trials to obtain a specific competency).

The results from this study should not be generalized to the real UAV pilot population without some caveats. First, all of the participants came from the Air Force Academy and all had a limited amount of flying experience. Flying experience of Academy cadets is significantly different than the experience of real UAV pilots. Second, even though the cadets had roughly the same amount of flying experience, there were individual differences in the time it took to complete the basic maneuvering task, indicating obvious skill variation among cadets. Some cadets took 15 minutes to complete the basic maneuvering task while others took up to 60 minutes. The difference in training could affect performance in the measured portion of the study.

This study lends itself to many areas of future research. One area to explore in the future is to create a more detailed feedback system through the tactile vest. The detailed feedback would include horizontal and vertical feedback to the UAV pilot during the whole landing approach. Another area to explore would be command vs. status feedback on the tactile vest. Command feedback would involve tactile feedback indicating the direction the pilot needs to fly, while status feedback just indicates the direction of error as implemented in this study. Comparing tactile feedback to better visual displays is another area of possible future research. In addition, a future study could examine if tactile feedback has the same effect on expert pilots.

A benefit of this study is examining the possible effectiveness of tactile feedback while operating UAVs. Since the study supports the notion that tactile feedback can be used to increase UAV pilot performance, then mishaps might be reduced. Reduced mishaps would lead to increased mission performance and lower the overall system cost

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