FIVE THINGS YOU SHOULD KNOW ABOUT SOLDIER – ROBOT TEAMING

Michael Barnes*[1], Florian Jentsch[2], Jessie Y.C. Chen[1], Ellen Haas[1] & Keryl Cosenzo[1]

[1]U.S. Army Research Laboratory, Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005

[2]University of Central Florida
Orlando, FL 32816

ABSTRACT

The Human Research and Engineering Directorate (HRED), U.S. Army Research Laboratory (ARL) and partner Tank and Automotive Research Development Command (TARDEC) embarked on a 5-year Army Technology Objective (ATO) research program that addressed human robot interaction (HRI) and teaming for both unmanned aerial vehicles (UAV) and unmanned ground vehicles (UGV). The program's objective was to understand HRI issues in order to develop technologies and mitigations that enhance HRI performance in future combat environments. In order to put the five year program in manageable perspective, we summarized five important HRI principles and supporting results that emerged from the research effort. The principles cover the benefits of teaming relations for robotic missions as well as crew multitasking problems associated with future robotic missions and possible solutions. We also discussed the importance of individual differences for HRI design and training implications and the advantages of multimodal interfaces and adaptive automation.

1. INTRODUCTION

Soldier robot teams will be an important component of future battlespaces, creating a complex but potentially more survivable and effective combat force. The Human Research and Engineering Directorate (HRED), U.S. Army Research Laboratory (ARL) and partner Tank and Automotive Research Development Command (TARDEC) embarked on a 5-year Army Technology Objective (ATO) research program that addressed human robot interaction (HRI) and teaming for both unmanned aerial vehicles (UAV) and unmanned ground vehicles (UGV). The program's objective was to understand HRI issues in order to develop technologies and mitigations that enhance HRI performance in future combat environments. The researchers have published nearly 100 individual papers to date and more continue to be published. In order to put the five year program in manageable perspective, we will summarize five important HRI principles and supporting results that emerged from the research effort.

2. THE IMPORTANCE OF SOLDIER-ROBOT TEAMING: TEAMS ARE BETTER

Researchers at the University of Central Florida (UCF) conducted seven simulation studies to investigate the importance of HRI teams for reconnaissance missions in a simulated Iraqi city. The researchers focused on robots emulating the size, weight, and functionality of the future Armed Robotic Vehicle (ARV), used mostly in a reconnaissance and surveillance role. In addition to studying operator teamwork among both mounted and dismounted robot operators and investigating operator-vehicle-ratios, the UCF researchers focused their investigations on operator training, mission planning, situation and spatial awareness, as well as aided target recognition, acquisition, and identification.

In the most extreme cases, two-person teams outperformed individual operators by nearly 200%, indicating synergy among team members, especially under difficult mission conditions. The efficacy of teaming aerial and ground assets was also demonstrated. Further, the UCF researchers demonstrated that the way in which operators of aerial and ground assets cooperate significantly affects the team's overall performance. For example, sharing of imagery from their assets did significantly improve the operators' coordinative processes and team performance above simply having text-based communications via datalink. Conversely, allowing the operators to also hand over control of their asset's payload to their teammate reduced performance and increased workload, under the worst conditions to a level as low as that observed when the operators only shared text-based communications.

Other successful mitigation strategies studied by the UCF researchers included training on ground and aerial perspectives, use of more effective pre-mission planning procedures, and prolonged (multi-session) practice in the task environment. For example, providing operators with comparatively brief training on the relationships between the views obtained from ground-based and aerial cameras not only improved operator performance in the task environment, but indeed was also associated with an

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 2008**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Five Things You Should Know About Soldier Robot Teaming**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Research Laboratory, Human Research & Engineering Directorate Aberdeen Proving Ground, MD 21005**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADM002187. Proceedings of the Army Science Conference (26th) Held in Orlando, Florida on 1-4 December 2008, The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

improvement of operator scores on standardized tests of spatial abilities. The latter, in particular, showed the importance of adequate, appropriate, and specific training for operators of ground and aerial unmanned vehicles. This at first seemingly obvious laboratory finding helped to explain the aforementioned performance decrements observed when operators of dissimilar assets could share control of their vehicles' sensors. The finding, however, also mirrored and validated prior, but purely anecdotal, evidence from field use where agencies operating unmanned vehicles had repeatedly found that they needed to expand their training courses with modules on the specific visual perspectives of the associated system sensors (REF). We concluded from the UCF research that even with increased automation and improved span of control, teaming among different robotic entities and their operators would remain an important consideration. On-going and future research will focus specifically on extending the teaming relationships among human operators of robotic assets to those among mixed human-robotic teams. The UCF scientists, for example, have already conducted coordination and communication needs analyses, not only among human operators and between them and their assets, but also with respect to the involvement of other human "cohabitants" in the mission environment. Future investigations will focus on identifying optimized task- and role-sharing among human and robotic team members, as well as the impact of technical advances on this type of teaming relationships.

3. THE IMPORTANCE OF MULTITASKING: ROBOTS NEED ATTENTION

Modeling studies including interviews with robotic experts at Ft. Knox indicated severe multitasking requirements for mounted Soldiers even without a robotic role (Mitchell & Henthorn, 2006). Chen and her colleagues investigated future crew stations for mounted vehicular systems using simulation resources at US Army Simulation & Training Technology Center (STTC). The purpose of the series of experiments was to determine: 1. effects of adding various levels of robotic tasks to the crew's multitasking environment 2. mitigation strategies to reduce workload and improve performance in this environment (Chen, Durlach, Sloan & Bowens, 2008; Chen & Joyner, in press; Chen & Terrence, 2008a; Chen & Terrence, 2008b). Their initial study compared controlling a semiautonomous unmanned ground vehicle (UGV), teleoperating the UGV and controlling a unmanned aerial vehicle (UAV), or being able to use all three assets (Chen et al., 2008). When participants were allowed to use all three assets, they did not take advantage of being able to use multiple viewpoints for targeting instead they tended to simplify attentional demands by relying on a single asset. This supported UCF's and other research findings (Murphy, 2004) indicating that coordinating more than a single robotic asset increased workload without resulting in performance gains. Interestingly, participants choose to use the UAV 3-1 over the semiautonomous UGV although their targeting performance using either as a single asset was equivalent. This indicates a clear preference for aerial views even when there is no performance advantage.

The next three studies investigated the attentional demands of varying the level of the robotic task difficulty while the crew concurrently conducted their primary task which was to use a separate gunner's display to find targets near the mounted system. Figure 1 shows that performance on the primary task was reduced as a nearly linear function of robotic task difficulty (Chen & Joyner, in press). Performance on the communications task and workload data followed the same trend. However, there were some interesting findings in the secondary task data. Chen's previous research indicated that when performed alone, teleoperations was the most difficult and attention demanding task compared to semi-automated conditions. However, teleoperations actually resulted in better targeting for the robotic task when the operator was required to split attention among multiple tasks. This implies that the operator focused more attention on robotic targets during teleoperations compared to automated control. However, the additional attentional focus during teleoperations had unacceptable cost for the primary task- operators missed threats close to the mounted system. This suggests that the effect of attentional demands of the various robotic tasks is not straightforward; the increased workload caused by manual control on the robot not only reduced attention in the primary task but also improved robotic targeting efficacy compared to more automated conditions.

In the next two studies, the effects of using automated target aiding (AiTR) was investigated as a means of alerting the operator to potential targets near the mounted vehicle (Chen & Terrence, 2008 a & b). The hypothesis was that the operator would share attentional resources more efficiently if cued to possible targets near his/her vehicle. Two cueing conditions were investigated: tactile cues indicating position of the potential threats on the gunners display and tactile plus visual display of the same information. Both cueing conditions worked equally well for most participants showing a significant increase in primary task performance from 52% to 84% correct target identifications. This indicates that overall the participants were able to use the eight cardinal points vibrating on the tactile belt to rapidly direct them to the target location on the gunner's 360 degree display (similar to a periscope). However, there were important individual differences that will be discussed in the next section.

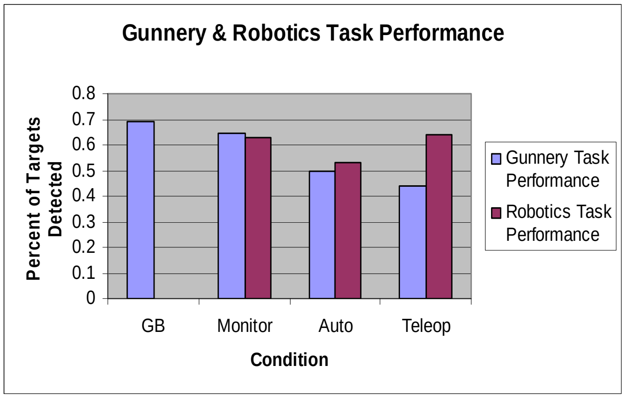
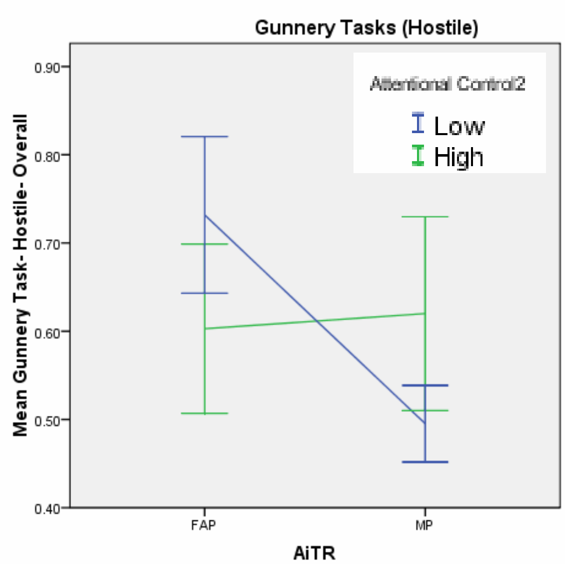


Figure 1. Comparison of baseline with different robotic conditions for both primary (gunner) targeting near the vehicle and secondary task (robotic) remote targeting. GB-baseline (no robotic tasks), MONITOR – monitored the robot only, AUTO- controlled robot with waypoints, TELEOP- teleoperated the robot to find targets.

4. THE ELEPHENT IN THE ROOM: INDIVIDUAL DIFFERENCES ARE IMPORTANT

A frequent criticism of psychology is that too often observed differences refer to mean differences whereas the underlying dynamics may be better represented by emphasizing individual rather than group effects. Our research at STTC and UCF investigated the effects of individual skill and attentional attributes on operator performance. The findings indicate that individual differences are crucial factors for HRI multi-tasking. In all experiments, participants with higher spatial ability performed HRI tasking more effectively than less spatially skilled participants. Apparently, their superior spatial awareness allowed them to switch efficiently from the remote terrain (robotic view) to the local terrain (mounted vehicle view). Some of the results were complex; tactile AiTR cueing was preferred by 65% of the participants but their preferences were related to spatial ability (Chen & Terrence, 2008a). Those with poorer spatial scores preferred the visual + tactile display combination suggesting that they had difficulties envisioning the spatial relationships between the robotic and gunner's displays without having the visual cues in addition to the tactile cues. The AiTR in Chen and Terrence (2008a) acted as bootstrapping mechanism, participants with poorer spatial abilities and those who were low in attentional focus scores received the most benefit from the AiTR. Their scores were similar to the high spatial ability group when the AiTR was available but were significantly worse without the aid. In Chen and Terrence (2008b), the reliability of the AiTR was manipulated. AiTRs with two types of unreliability were compared: miss-prone (MP) and false-alarm prone (FAP) AiTRs both having an overall reliability of 60%. The most interesting findings resulted from individual differences in perceived attentional control (PAC) scores which measured confidence in the ability to focus attentional resources. There was a distinct type X interaction between types of AiTR and high and low PAC scores for both the gunner (primary) and the robotic (secondary) target detection performance (Figure 2). Relative to low PAC participants, the high PAC ones performed better with the miss-prone aid than with the false-alarm prone aid. Apparently, their confidence in their own attentional abilities made them uncompliant with FAP aids even when the aids might be helpful but trust in ther own attentional abilities made them monitor the MP aids more effectively. Participants with lower PAC scores had the reverse detection strategy; they complied with FAP aids more effectively but tended to over rely on the MP aids resulting in poorer target detection performance. Because there was no main effect of type of aid, we can conclude that the manner in which individuals responded to the different types of unreliability (FA or misses) was the crucial factor in determining target detection performance. The results seemed to be related to individual differences in automation trust– the high PAC operators being less trusting did not use the FP device optimally (disuse) whereas the low PAC operators were too trusting failing to monitor possible AiTR misses optimally (misuse) (Lee and See, 2004). We concluded that skills related to future robotic operations are highly individualized and that decision aids, selection criteria, and specialized training need to be tailored to individual abilities and personality factors rather than assuming that one size fits all.

(a)



(b)

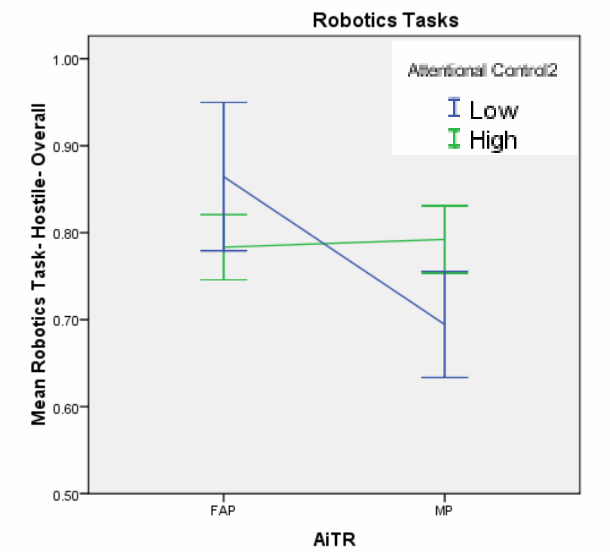


Figure 2. Interactions between AiTR type of unreliability and PAC for (a) the gunnery task performance (b) the robotics task performance.

5. NON-TRADITIONAL INTERFACES: FINDING UNDERUSED RESOURCES

Multimodal interfaces involve the use of more than one modality in control and display interfaces. Multimodal interfaces have proved to be useful in demanding HRI environments such as the Army battlefield, where auditory warnings and/or tactile cues may be used when the Soldier experiences visual overload, or has no access to visual displays.

Early robotic systems used unimodal visual feedback. Auditory cues were developed as awareness grew that additional modalities could supplement the visual channel when it was heavily loaded. Chong, Kotoku, Ohba, Sasaki, Komoriya, and Tanie found that by adding audio to visual feedback, teleoperators could more easily detect the possibility of collision and coordinate conflicting motions between multiple robots. Researchers also found that providing spatial auditory cues which can enhance UV-related tasks such as maintaining 360-degree situation awareness around a robot. Tactile displays, which use pressure or vibration stimulators that interact with the skin, are also a promising modality for providing warnings for robotic systems, as well as provide spatial and positional information beyond the field of view. Tactile cues have been used to provide safety warning information and communicate information regarding orientation and direction (Cholewiak and Collins, 2000). Calhoun, Fontejon, Draper, Ruff and Guilfoos found that tactile displays can significantly improve detection of faults in unmanned aerial vehicle teleoperation control tasks, and can serve as an effective cueing mechanism.

Army Research Laboratory researchers found that there are several advantages to integrating audio and tactile displays in challenging applications such as moving vehicles. Haas, Stachowiak, White, Pillalamarri, Feng (2007) conducted a field study at the ARL to determine the extent to which the integration of spatial auditory and tactile displays affects soldier situation awareness in a simulated UV HRI target search task performed in a moving HMMWV traveling over gravel and cross-country terrain. The objective of the study was to determine whether tactile and 3D audio technologies could effectively convey information in moving vehicle environments that contain relatively high levels of vibration and jolt, and to examine the extent to which vehicle (HMMWV) operations affect user performance with multimodal cues. Data indicated that performance time and accuracy with the tactile display were not limited by movement or vibration on the gravel or cross-country terrain. Results indicated that for the target search task, tactor output was not masked by participant contact with the seat back during vehicle bumps on the gravel or cross-country terrain. Results also indicated that participants rated combination tactile + audio displays as having a significantly lower workload than audio and the tactile displays used separately (Figure 3). One reason for the significantly lower auditory + tactile workload rating may have been that the combination audio + tactile display incorporated cues from both audio and tactile modalities, allowing one display modality to provide cues because the combination is more powerful in an environment with strong auditory and tactile distracters.

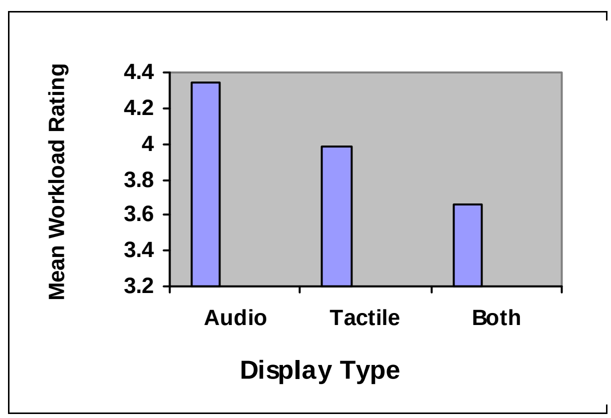


Figure 3: Mean workload rating as a function of display type

Haas, Stachowiak, White, Pillalamarri and Feng (2008) conducted a study to determine whether tactile displays can provide the user with multiple dimensions of information. These researchers found that tactile displays which use temporal (rhythm) cues can provide multiple dimensions of information simultaneously, and recommended different information coding that could efficiently and effectively provide multiple levels of information. Their current research explores the integration of audio and tactile displays that integrate multiple levels of information.

6. ADAPTIVE AUTOMATION: IT REDUCES WORKLOAD AND IMPROVES SA

One obvious solution to multitasking in future systems is to automate functions. However, previous research indicates that too much automation results in complacency and reduced SA because the operator is "out of the loop" (Barnes, Parasuraman & Cosenzo, 2006). Researchers from George Mason University and HRED investigated the possibility of using adaptive automation in a robotic environment. They investigated model-based and performance-based triggers to automate UAV functions during high workload portions of robotic missions (Parasuraman, Barnes & Cosenzo, 2007). The robotic operator taskings included monitoring ground robot movements, targeting with UAVs and conducting communications tasks. They were also monitoring changes in symbol locations on the situation display. This is a representation of the type of cognitive tasks a robotic operator would be performing as a crew member of a mounted system .The adaptive aid was compared to static automation and to manual conditions. The process that we adaptively automated was the UAV target recognition task. The adaptive trigger was performance based – UAV targeting was automated (AiTR) when the operator failed to notice changes in his/her situation display suggesting overload. This was compared to a mission segment in which automation was always invoked and to manual target detection in the same mission segment.

As Figure 4 indicates performance- based adaptive automation was superior to manual and to static automation conditions. This supported the general hypothesis that automating adaptively keeps the operator in the loop thus improving situation awareness compared to full automation which may result in automation complacency and inattention (Barnes et al, 2006; Parasuraman et al. 2007). The results of five experiments revealed generally consistent evidence for the efficacy of adaptive automation in supporting human operator supervision of multiple robots. More recently we investigated neuro-sensing triggers as well as performance based ones in more realistic scenarios at UCF. We concluded that some type of flexible automation for either the interface or for robotic taskings is a promising solution to keeping the operator in the decision loop while reducing workload. Automation may be successful not only in supporting the human operator in his primary robotic task but may also free up sufficient attentional resources to benefit performance on the sub-tasks.

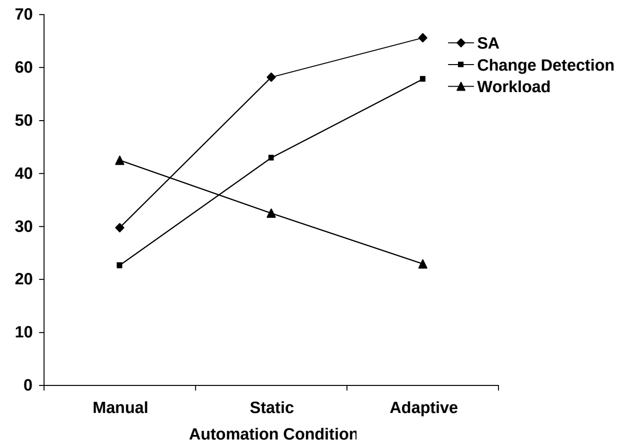


Figure 4. Effects of static and adaptive automation on change detection accuracy, SA, and mental workload. From Parasuraman et al. (2007).

7. SUMMARY AND CONCLUSIONS

The corpus of the research suggests that HRI is a complex process involving interactions between humans and robots but it also involves interactions among human team members. Jentsch and his colleagues showed that single operators can be overwhelmed by the SA demands of reconnaissance missions in urban environments even in semi-autonomous driving modes. Team members who shared imagery from different systems (UGVs and UAVs) showed considerable performance gains but surprisingly being able to share control had almost as large a negative impact. Working with different systems also required operators to adjust to variant visual perspectives; however, UCF researchers showed that even minimum training of the correct type leads to rapid improvements in understanding perceptual features from multiple perspectives.

Chen (ARL) and her colleagues investigated single operators in complex environments that required already heavily overloaded operators to conduct robotic missions in addition to other multitaskings. Their results indicated that each increment in robotic task difficulty resulted in crew members missing additional targets in their immediate environment. Tactile target cueing improved performance allowing the operator to task share more efficiently. However, further analysis revealed that HRI performance depends on individual differences. Target cueing had it is greatest effect on operator's with low spatial ability and poor perceived control. In those cases, cueing bootstrapped poor performers to near equivalency to operator with higher scores on both indexes.

Cursorily, individual differences in automation-trust and self-confidence were responsible for differences in operators' responses to unreliable AiTR's false alarms and misses. The important point is HRI depends not only on human robot issues but also differences inherent in human populations.

A variety of techniques were investigated to improve HRI performance. Multimodal research indicated that tactile augmentation of visual displays was the most effective workload reduction mechanism for target location tasks even in severe vibratory environments. However, there were redundancy advantages to adding spatial audio target location cues to the mix. Other Haas' studies showed the advantages of non-redundant multimodal cues and the feasibility of tactile display of multidimensional information.

Different types of automation were investigated to reduce workload while maintaining overall situation awareness during complex HRI multitasking conditions. Parasuraman et al's (2007) results supported the use of adaptive automation triggers that were tailored to individual robotic operator performance during high workload mission segments. More recent adaptive research manipulated physiological as well performance based indices for invoking automation. The general findings support the use of systems that adapt to changing workload demands in contrast to fully automated mission segments.

REFERENCES

Barnes, M., R. Parasuraman, and K. Cosenzo. (2006). Adaptive automation for military robotic systems. In NATO Technical Report, *Uninhabited military vehicles: Human factors issues in augmenting the force* (NATO Publication No. RTOTR-HFM-078, pp. 420–440).

Chen, J. Y. C., P. J. Durlach, J. A. Sloan, and L. D. Bowens, in press: Human robot interaction in the context of simulated route reconnaissance missions. *Military Psychology, 20*(3), 135-149.

Chen, J. Y. C., & Joyner, C. T. (in press). Concurrent performance of gunner's and robotics operator's tasks in a multi-tasking environment. *Military Psychology.*

Chen, J. Y. C. & Terrence, P. I. (2008a). Effects of tactile cueing on concurrent performance of military and robotics tasks in a simulated multi-tasking environment. *Ergonomics, 51*(8), 1137-1152.

Chen, J. Y. C., & Terrence, P. I. (2008b). *Effects of Automation Reliability on Concurrent Performance of Gunnery and Robotics Tasks* (ARL Tech Rep. ARL-TR-4455). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Chen, J. Y. C., Haas, E. C., & Barnes, M. J. (2007). Human performance issues and user interface design for teleoperated robots. *IEEE Transactions on Systems, Man, and Cybernetics--Part C: Applications and Reviews, 37*(6), 1231-1245.

Calhoun, G., Fontejon, J., Draper, M., Ruff, H., and Guilfoos, B. (2004). Tactile versus aural redundant alert cues for UAV control applications. *Proceedings of the Human Factors and Ergonomics Society 48th Meeting* (pp. 137-141).

Cholewiak, R. W., and Collins, A. A. (2000). The generation of vibrotactile patterns on a linear array: Influences of body site, time, and presentation mode. *Perception and Psychophysics, 62,* 1220-1235.

Chong, N.Y, Kotoku, T., Ohba, K., Sasaki, H., Komoriya, K., and K. Tanie, K. (2002) "Multioperator teleoperation of multirobot systems with time delay. II – Testbed description," *Presence: Teleoperators and Virtual Environments, 11*(3), 292-303.

Elliott, L. R., Redden, E.S., Pettit, R., Carstens, C., and Van Erp, J. (2006). *Tactile Guidance for Land Navigation.* Manuscript submitted for publication, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD.

Haas, E.C., Stachowiak, C., White, T., Pillalamarri, K., and Feng, T. (2007). *The Effect of Vehicle Motion on the Integration of Audio and Tactile Displays in Robotic System TCU Displays.* Unpublished manuscript, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD.

Haas, E.C., Stachowiak, C., White, T., Pillalamarri, K., and Feng, T. (2008). *Multimodal Signals To Improve Safety and Situational Awareness in a Multitask Human-Robotic Interface.* Unpublished manuscript, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD.

Lee, J. D., & See. K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors, 46*, 50-80.

Mitchell, D. and Henthorn, T. (2005). *Soldier workload analysis of the mounted combat system (MCS) platoon's use of unmanned assets* (ARL-TR-3476). Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Murphy, R. R. (2004). Human-robot interaction in rescue robotics. *IEEE Systems, Man and Cybernetics Part C: Applications and Reviews, Special Issue on Human-Robot Interaction 34* (2), 138-153.

Perrott, D.R., Sadralodabai, T., Saberi, K., and Strybel, T.Z. (1991). Aurally aided visual search in the central visual field; effects of visual load and visual enhancement of the target. *Human Factors, 33*(4), 389-400.

Parasuraman, R., Barnes, M., & Cosenzo, K. (2007). Adaptive automation for human robot teaming in future command and control systems. *International Journal of Command and Control, 1(2),* 43-68.

White, T.W., and Krausman, A. (2006). *Detectability of vibrotactile signals in moving vehicles.* Unpublished manuscript, U.S. Army Research Laboratory, Aberdeen Proving Ground, Maryland.