Comparing Training Performance With Vibrotactile Hit Alerts vs. Audio Alerts

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ABSTRACT

Live, virtual, and constructive training that integrates dismounted warfighter training with convoy training, pilot training, and other systems has been demonstrated to reduce training time, and studies have shown that a high level of immersion and the illusion of presence in a VR environment contribute to this success. However, current force-on-force training simulators lack one major quality that is needed to impart this strong sense of presence for warfighters: the consequence of getting shot.

Simulated return-fire systems have been developed for different purposes including military, police and entertainment. Some use projectiles, but that approach is usually limited to a shoot house configuration rather than outdoors. Other methods use on-body electrodes to provide electric shock or tactors that physically strike the body using solenoids or pneumatics. These systems face challenges of either low body localization (with a small number of tactors) or tethering (if a real-time connection to electricity or air is needed to power the tactors).

In this paper, a tactile vest containing commercially available vibrating pagers is evaluated. These pagers allow a focused alert to be given to a Warfighter, indicating the bodily location of the shot and appropriate direction for return fire. They are also cost-effective and easily replaceable. The evaluation included a simple training mission while receiving either vibrotactile feedback vs. auditory spoken alerts of virtual sniper hits and direction of fire. Results showed that a tactile vest made from commercial off-the-shelf pagers performed well as an indicator of fire and could be viable option for integration with future LVC training, especially given its low cost. Also, results suggested that there may be strong individual differences between people in terms of their ability to process vibrotactile vs. auditory feedback while cognitively loaded.

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INTRODUCTION

In this paper, a tactile vest containing commercially available vibrating pagers is evaluated for use in a live or virtual training environment. These pagers allow a focused alert to be given to a warfighter, indicating the bodily location of a shot and appropriate direction for return fire. Live, virtual, and constructive training that integrates dismounted warfighter training with convoy training, pilot training, and other systems is becoming a critical part of a warfighter's preparation. However, current force-on-force training simulators lack one major quality that is needed to impart this strong sense of presence for warfighters: the consequence of getting shot.

The following research study presents an evaluation of commercial-off-the-shelf vibrating pagers embedded in a vest as a tactile hit-alert system within a virtual training mission. We propose that for a tactile hit-alert system to be effective, it must satisfy the following criteria:

1. The alert should be distinctly noticeable, if not markedly irritating.
2. The alert should be minimally confusable with other stimuli the warfighter faces (uniqueness).
3. The alert should not block the perception of other stimuli the warfighter faces (non-masking).
4. The system should provide spatial localization on the body, to indicate location of the hit.
5. The system should not provide significant extra weight or bodily imposition on the wearer.
6. The system should respond with low latency and low refractory period.
7. The system should be cost effective.

BACKGROUND

Prior to constructing a tactile feedback device for warfighters in training, a review of current return-fire training methods was required. Methods that use actual projectiles (e.g., Patent US5980254) and systems that use tactors worn on the body of the user (Corley, 2010; "Threat-FireTM | Virtra," n.d.; "TN Games," n.d.) are the first distinction between return-fire systems. Another feedback method is electric shock, as seen on the Threat-Fire^{TM} (Virtra).

Many different torso-based tactile garments that do not electrocute the user have been developed both commercially and for research. The "3RD Space Vest" from TN Games and the "Tactile Gaming Vest" (TGV) from students at the University of Pennsylvania (Corley, 2010) are focused on gaming and entertainment. The tactile feedback vest designed by researchers at the University of California, Los Angeles Center for Advanced Surgical and Interventional Technology (Wu et al., 2010) and the tactile band designed by the University of Michigan (Lee et al, 2011) were developed for research for patients with vestibular disorders. A vest designed by ACME Worldwide is used to simulate g-forces for pilots (Sutton et al, 2010). The vest designed by researchers at Massachusetts Institute of Technology (MIT) was used to assist navigation (Jones et al, 2006). Finally, a vest designed by researchers at Iowa State University integrated multiple impact tactor designs to study the best method to deliver simulated bullet hits to warfighters in training (Prater, 2012; Prater, D., Gilbert, S., & Winer, E., 2013). Although they vary in feedback delivery and overall intention, many of these tactile vests share the common tactile delivery method of vibratory feedback. See Table 1 for a comparison of the tactors used in these vests.

MILES, a training system for Soldiers with components affixed to a weapon and worn on the body to transmit and receive infrared (IR) "bullets", has been used by the United States Military since the 1980s. These IR bullet signals are interpreted by a central system that indicates whether Soldiers have been hit during the exercise. Due to the simplicity of the technology, the system cannot differentiate between wounding hits and lethal hits. Therefore every hit is interpreted as a kill. In 2012, MILES was officially superseded by the I-TESS II, a new system with much more functionality. Although the I-TESS II can distinguish wounding hits from kills while providing real-time data to facilitate an after action review, it was not designed to integrate easily into virtual or mixed reality training environments. Additionally, both of these training systems lack a physical tactile interface with the trainee to indicate when an enemy has successfully fired a shot at them. These systems instead rely on an audio alert that indicates the trainee received a hit. Anecdotal feedback from military trainees indicates that physical feedback is a desirable feature that is missing from these solutions. In the context of training military troops with a system like I-TESS II, feedback could be used to quickly relay the time, location, and severity of a wounding shot received by the trainee.

Table 1. Comparison of tactile garments

Type of Tactor	Garment							
	TGV	3RD space vest	ACME Worldwide Vest	UCLA tactile Vest	MIT tactile band	U. Michigan tactile band	Iowa State Vest by Prater	Iowa State Pager Vest
Vibrotactile	X				X	X		X
Electromagnetic Impact Tactor	X						X	
Pneumatic Tactor		X	X	X				
Peltier Element	X							

A review of tactile feedback delivery methods used in other research shows that in general, a user-worn delivery method is ideal. Other systems that were explored include ultrasonic tactile stimulation of the user. This is an appealing solution because it theoretically requires no additional user-worn equipment and does not rely on physical projectiles launched towards the user. The use of ultrasound to deliver haptic feedback, however, is thus far limited to operate in a single axis and would tether a trainee to a specific area (Hoshi, et al, 2009). The output is a relatively low amount of force across a small distance (Iwamoto, et al, 2004). Additionally, high intensity ultrasound is known to damage blood vessels (Hynynen et al, 1996).

While we have not personally evaluated each of the vests in Table 1, it is possible to evaluate them based on some of the seven criteria above based on their architecture. For example, systems with pneumatic tactors will fall short on Criterion 5 because of the bodily imposition of a tethered air hose. Likewise, systems that provide a single peltier element or small number of tactors will not satisfy Criterion 4 to provide spatial localization. However, vibrotactile systems, with less jarring alerts than electric shock, may not satisfy Criterion 1 as well (being noticeable and irritating).

TEST EQUIPMENT AND METHODOLOGY

The study compares participants' ability to identify a sequence of target locations based on cues delivered through either a replica military-style plate carrier fitted with vibrotactile actuators (the tactile vest) or audio cues through a standard PC speaker system. The research team fabricated a suitable tactile vest based on a review of the current tactile vests listed in the background section. The vest was designed to deliver a vibrotactile sensation to the user via pairs of commercial-off-the-shelf vibrating pagers embedded in three discrete locations: the chest, the left shoulder, and the right shoulder (see Figure 1). The pagers were controlled by our testing software through radio frequency communication. While several of the return-fire methods described above are capable of providing the user with a more jarring stimulus to serve as

Figure 1: Commercial off-the-shelf pagers were embedded within the vest, two per indicated region.

a behavior deterrent, the pagers used in the vest provide a noticeable but pain-free amount of vibrotactile feedback to the user. In the context of the study, the pagers indicate whether a trainee has been shot, as well as the direction of enemy fire.

To simulate the rigidity of actual armor, a fitted piece of plywood was placed in the vest's trauma plate pocket. The two pagers located in the central portion of the vest were embedded in an area cut out of the center plywood piece. The vest had enough padding that a user does not feel the presence of the thin pagers until they vibrate. The pair of pagers located on each shoulder are strapped into an existing part of the vest's harness. While the shoulder pagers are visible if looking inside the shoulder harness, the participant does not feel them until they vibrate.

The pagers weighed 66 grams (0.15 lbs) each, totaling 396 grams (0.9 lbs) of additional weight for the six pagers used in this study. Each pager cost $30, for a total cost of $180 per vest. (The multi-pager charger and base transmission unit cost approximately $400.) The pager battery specifications state that they hold a charge for 6-8 hours of moderate usage, and require the same amount of time to recharge. In this study we did not fully deplete the batteries to test those specifications.

Optical Tracking Equipment

The study combines tracking technology developed in Iowa State University's existing LVC research environment, the Veldt (Newendorp, 2011) with the new vibrotactile vest and new software. Position, orientation, and movement of the participant and the participant's replica weapon are tracked in real-time with an array of four ART TRACKPACK cameras and one ART SMARTTRACK. The cameras project IR light, which is then reflected off of reflective markers attached to the helmet and weapon. Trigger pull events were tracked using a Radio Frequency (RF) remote clicker that was placed inline with the trigger. This technique allowed us to accurately detect each trigger pull within our software within milliseconds of the trigger being pressed, as well as repeatably, as fast as the user could pull the trigger. Pagers were activated using an RF transmitter connected with our software. They had no noticeable latency, though they did have a refractory period of approximately 1-2 seconds while the system waited to confirm that the pagers had received their activation signal. Monophonic auditory cues for the participant were provided through a set of standard PC speakers. These speakers indicate when the participant should advance to the next step of the study and also relay information about the direction of enemy fire during the audio condition.

Methodology

For this study we recruited 31 participants, four of whom were members of the Iowa Army National Guard. Others were civilians ranging in age from 19 to 60. Once participants signed consent and completed a brief demographic survey, they were outfitted with the trackable replica military-style helmet, the trackable replica weapon, and a tactile vest.

The overall goal of the study was to determine whether tactile feedback or audio feedback on a task would enable a potential warfighter to perform a task more effectively. In this case, to test Criteria 2 and 3 specificially, we chose a 10-step sequence memorization task. Given limited working memory (Miller, 1956), we considered 10 steps to be difficult and to require higher-level cognitive processing for memorization.

The two stimuli sources were separate test conditions, each with a training phase and a response phase. During each test condition, the participants advanced through a series of 10 consecutive linear positions spaced two feet apart, each of which have a simulation of an enemy fighter firing at the participant from a random selection of one of three possible directions: left, right, or center. The test layout is shown in Figure 2.

Prior to data collection, the participant was given a brief three-position tutorial to become familiar with the testing environment and procedure. Once the tutorial was complete, the participant was exposed to the training phase of the study, during which he or she moved to each of the 10 positions to memorize the direction of the enemies. The participant was informed of the enemy location at each of the 10 positions by the feedback method associated with the current test condition - either the tactile vest for localized vibrotactile feedback or the speaker system for audio feedback. An audio alert from the software indicated the participant was free to move to the next position once he or she had experienced the feedback for the current position. This process continued until the participant was trained at all 10 positions.

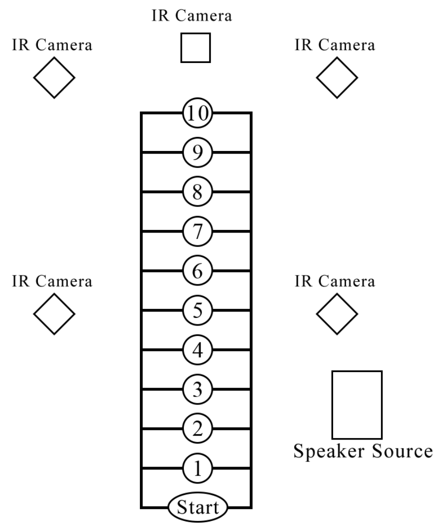

Figure 2: The floor plan of the testing area. Participants moved from Start to 10, engaging a virtual enemy at each step who was either to the left, right, or ahead of the participant.

Once the participant was trained, the response phase began. During the response phase, participants again moved through all 10 positions, but they were given no reminder of where the enemy is located, and instead indicated the direction of the enemy by firing their replica weapon either left, right, or center. If an error was made, the participant immediately received feedback that indicated the enemy location for the current position, and the participant continued through the remaining positions. A participant who made one or more errors during the 10-step response phase had to repeat the 10-step attempt until passing through all 10 positions with no errors. Although there was no limit on the number of attempts a participant was allowed, an upper time limit of five minutes was imposed on the response phase of each task.

To compare the effectiveness of vibrotactile instruction and audio instruction, each test participant completed two consecutive training exercises with either vibrotactile or audio instruction cues. The enemy positions were different in each exercise. The order of feedback methods was nevertheless counterbalanced to account for a potential learning curve. After the two training exercises were complete, the participant completed a written post-study survey as well as an oral interview; both were used to gain insight on the experience of the tactile vest and the audio feedback for each user.

Our hypothesis was that vibrotactile feedback would be more effective than audio feedback during this task. Given this, we expected to see fewer mistakes, fewer attempts before mastery, and smaller task completion time for virbrotactile feedback.

Results

Because of technical system errors, seven participants (including one National Guardsman) had to be excluded from data analysis, leaving 24 participants, including three National Guardsmen. Because participants' performance could be measured by number of 10-step attempts required before mastery, number of mistakes, and time on task, we created a performance raw score based on the sum of the three of those. We then normalized and inverted raw scores based on the highest and lowest raw score to create a final performance score for each participant (see Figure 3). A performance score of 1.0 was the best possible score, and 0.0 was the worst possible score. To give a sense of the range, the worst scoring participant on tactile (#29) made seven attempts and 24 mistakes and timed out without succeeding. A perfect scoring participant on tactile, on the other hand, e.g. #10, made one attempt, zero mistakes, and completed mastery in 19.64 seconds. It is worth noting that our military participants' data were not distinguishable from our other data. Participants are grouped in Figure 3 according to which condition they experienced first, so that it is visually apparent that performance was not correlated with the treatment order. For example, a given participant's better performance was not always in the second condition.

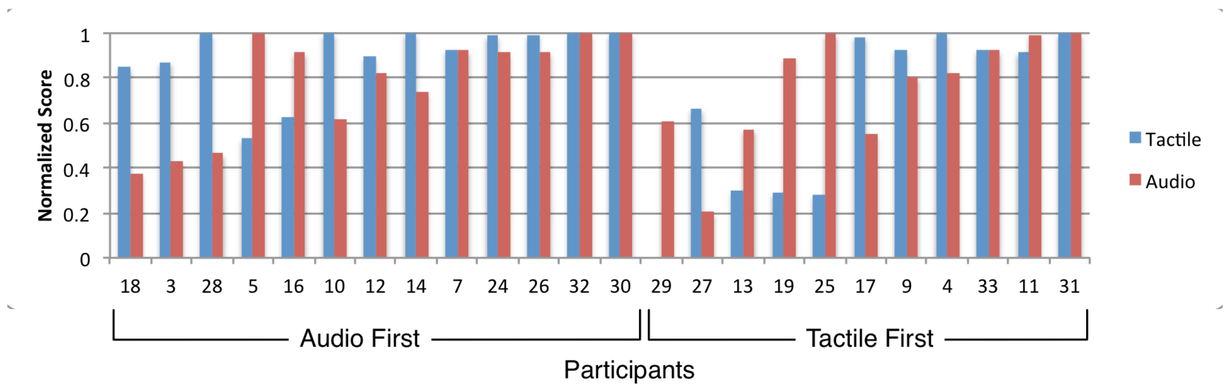

Figure 3: Participants' normalized performance, grouped by those who did the audio treatment first and tactile treatment first. There was no correlation between order and performance.

Figure 3 also illustrates that neither tactile nor audio were a clear performance winner. Participants in one condition did not consistently out perform participants in the other condition. The mean score for tactile (0.79, SD=0.30) and mean score for audio (0.77, SD=0.23) were not significantly different. However, we believe that individual differences may be an important factor in this research. According to the post-surveys, many participants had strong opinions about which condition was preferred. Specifically, 14 people explicitly preferred tactile feedback, four people explicitly preferred audio feedback, and six people were neutral. When participants are grouped by these categories, a more significant difference is found between performance with tactile feedback vs. audio feedback (see Table 2). Those who preferred tactile feedback performed statistically significantly better on their tactile test than audio test. Those who preferred audio performed better in that mode than with tactile. That difference is not quite statistically significant, but is close, and might rise if there were more participants in that category. There was no significant difference between treatments among those who didn't have a strong preference. It might seem obvious that people prefer the modality in which they perform better. However, this result is a cue that some individuals may have a learning or cognitive trait that leads them to perform dramatically different in one modality than in the other.

Table 2: Mean tactile and audio performance scores for groups that preferred a particular modality.

	Mean Tactile Score (SD)	Mean Audio Score (SD)	*p*-value
Preferred Tactile (*n*=14)	0.89 (0.19)	0.67 (0.25)	0.018
Preferred Audio (*n*=4)	0.59 (0.26)	0.93 (0.05)	0.080
No preference (*n*=6)	0.70 (0.44)	0.89 (0.15)	0.354

It is worth noting that between the tactile attempts and audio attempts, the pattern of errors was different. Figure 4 shows the average errors per attempt. Visually it can be seen that while the number of errors in each mode is similar during the early attempts, as the attempts continue, participants seem to have fewer errors per attempt in the audio condition, but those errors last longer than in the tactile condition. While this interaction effect did not reach significance ($F(9, 207)=0.38$, $p=.944$), this result suggests that with more participants we might see longer learning curve with audio, with a shorter learning curve with tactile feedback, but more errors along the way.

It is also worth noting where errors occurred and whether participants struggled with errors differently in the different modes. Figure 5 shows the distribution of participants' errors across the 10 steps of the exercise. Most errors were made in steps 7-9, when someone trying to memorize the sequence of numbers might typically begin to feel challenged. However, the pattern of tactile errors vs. audio errors is somewhat different, with more tactile errors earlier on in the steps. This pattern suggests, again, that individual differences in participants' abilities to process audio vs. tactile feedback may be an important issue to pursue. However, this interaction between modality and step did not reach statistical significance, $F(9, 207)=0.98$, $p=.461$.

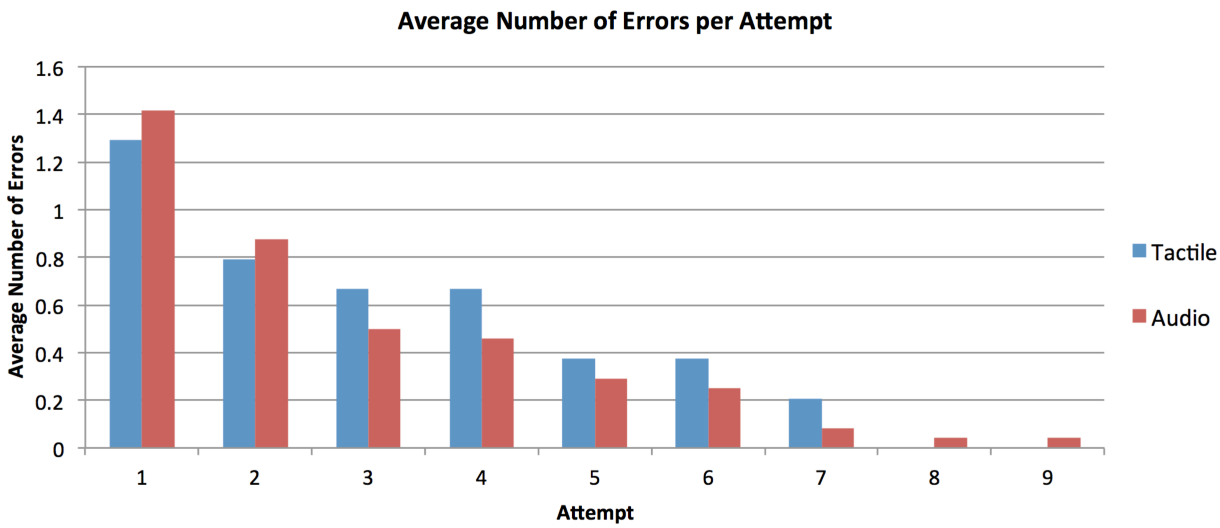

Figure 4: Average number of errors per attempt falls in both modes, but in tactile there is a slight tendency to make more errors earlier and master the task with fewer attempts.

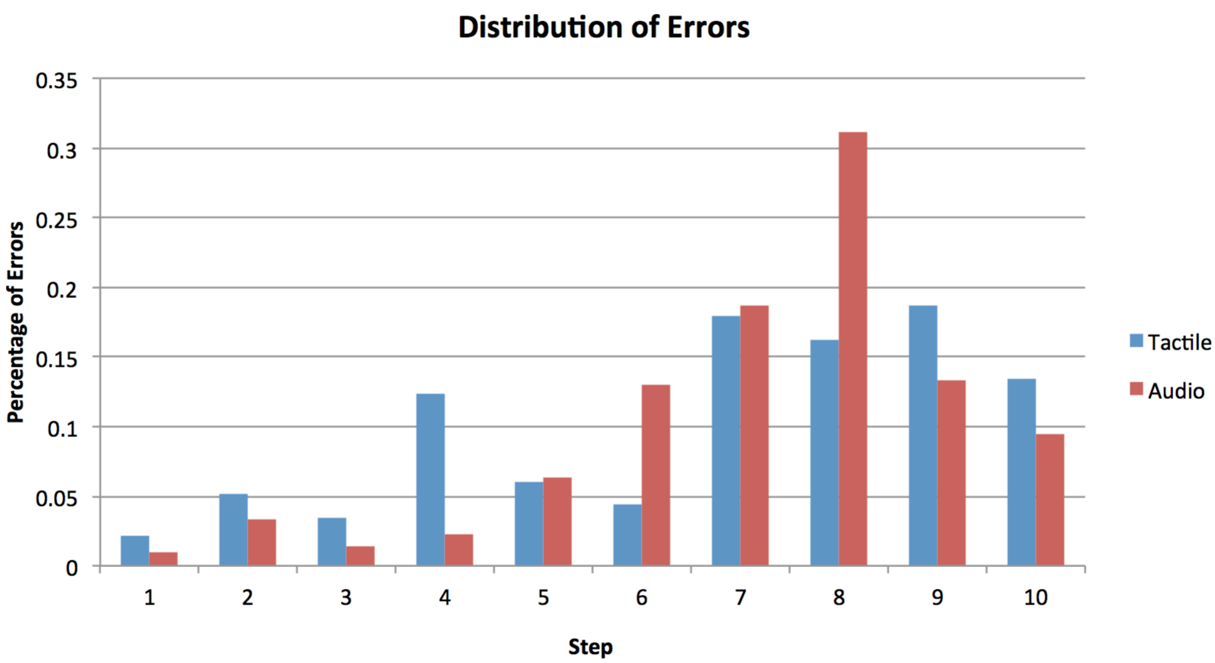

Figure 5: Most errors were made in steps 7, 8, and 9, but the different distribution of errors between the modes may suggest a role for individual differences in feedback evaluation.

Finally, it is worth describing data from the post-surveys. Military participants were cautiously optimistic, noting that using the tactile vest with MILES and EST 2000 would "be great" and that it wouldn't work like MILES, where equipment has to go over the vest. They wanted stronger vibrations, and they suggested testing it in other combinations of typical training settings. One noted that he liked the idea of the tactile vest signaling where a round was coming from, comparing it with the Wolfhound system. Civilian participants in the post-survey mostly expressed their preferences with one mode or the other, often expressing frustration with the alternative mode. Several noted that the tactile mode seemed "fun." Several noted that the audio feedback was problematic because they were trying to remember the sequence by repeating words to themselves such as, "Left, Center, Left, Left, Right…" and that the audio feedback interrupted those words, while the tactile feedback didn't.

CONCLUSION

This research study demonstrated that a tactile vest constructed with commercial-off-the-shelf pagers can be an effective and often preferred method for receiving feedback within a task that requires noticeable cognitive load. We suggest, however, that this very narrow result can generalize somewhat based on the initially stated criteria for a successful return-fire system. For Criterion 1 (noticeable and irritating), the tactile vest ranked medium. While obviously it was noticeable in this task context, Soldiers wanted it stronger and tested in other more realistic contexts. No one deemed it irritating. Our study did not explicitly address Criterion 2 (minimally confusable), but the tactile vest would likely score well in tasks in which there was no other tactile feedback. On Criterion 3 (that the vest's alert doesn't mask other information), the vest did perform well, and participants did explicitly prefer it to audio feedback, which sometimes masked their processing of the sequence memorization task. The vest performed relatively well for Criterion 4, spatial localization of the hit on the body, though it identified only three hit zones. That number could be increased, limited by the size of the pagers. The vest performed well in terms of Criterion 5, minimizing weight and imposition on the wearer. One Soldier commented that he would prefer such an arrangement to MILES, where the equipment adds a noticeable weight and burden to existing gear. The vest ranked medium on latency and refractory period because, while there was no noticeable latency, there was a refractory period that would prevent a wearer from receiving a quick barrage of pulses. Lastly, for Criterion 7, the vest offered an outstanding cost value, given that pagers were $30 each at purchase time. In summary, the vest performed well or medium well on all criteria, and has a very low cost. It is to be recommended as a method of offering feedback during training.

Secondly, in terms of the research study, we also learned that there seems to be significant differences among individuals in terms of their ability to use vibrotactile feedback. Therefore, it may be important to have alternative options for individuals so that those who do not perform well with modality (e.g., vibrotactile) would have another modality available.

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