Protecting Workers with Smart E-Vests

Kristen Hines
Virginia Tech
Blacksburg, VA 24060 USA
kphines@vt.edu

Wallace Lages
Virginia Tech
Blacksburg, VA 24060 USA
Fed. Univ. of Minas Gerais
Belo Horizonte, MG, Brazil
wlages@vt.edu

Namitha Somasundaram
Virginia Tech
Blacksburg, VA 24060 USA
snamitta@vt.edu

Thomas Martin
Virginia Tech
Blacksburg, VA 24060 USA
tlmartin@vt.edu

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Abstract
This paper describes the design and evaluation of an alerting vest for construction workers. Four different alerts and modalities were compared through an empirical study. We measured the response time to different alerts while the users performed three distinct tasks. We found that the modality of each alert has a significant effect on time and also observed a significant interaction between the alert type and the task being executed.

Author Keywords
Notification interfaces; wearable; multimodal; response time

ACM Classification Keywords
H.5.2. User Interfaces;

Introduction
Construction workers on roadside construction sites are frequently in danger of being struck by passing cars. These workers perform physically demanding tasks in all weather conditions and sometimes in areas where appropriate signage is limited or not present [1].

The United States Bureau of Labor Statistics reports 683 worker fatalities at road construction sites from 2008 to 2013. Transportation incidents accounted for

This picture shows the conceptual design for the vest. Colored squares show the approximate placement of output devices: Green and blue - vibrating motors; Black-speakers; Yellow LEDs. The general placement stayed the same in the finalized vest.

sixty-six percent of roadway work zone fatal occupational injuries in 2013. In sixty-nine percent of these transportation incidents, a pedestrian worker was stuck by a vehicle. Backing vehicles accounted for 27 of the 48 pedestrian vehicular incidents. In 2013, sixty-three percent of occupational fatalities in work zones were to the following occupations: construction laborers, highway maintenance workers, heavy and tractor trailer truck drivers, first-line supervisors of construction an extraction workers, and construction equipment operators. [2]

Due to noise, visual obstruction, mental workload, and environmental conditions, workers have difficulty perceiving approaching cars that are on a trajectory to strike them. Drivers, on average, respond to unexpected highway emergencies in 1.5 seconds going around 55 mph [3]. Therefore, warning individuals early about possible incidents is imperative. Previous work has shown that GPS units can be used to accurately estimate the trajectory of cars and warn workers about imminent strikes [4]. In this paper, we investigate the best way to notify workers of impending danger of being struck by passing cars. The focus was on construction workers on foot engaged in activities near the road, but the approach can be expanded to include police officers, first responders, and roadside maintenance workers.

Design Restrictions and Assumptions

Before we started the design, we made some assumptions regarding how the alerting mechanism would be used and how it would be integrated with the remaining system. These assumptions were based on the information derived from the Bureau of Labor Statistics and personal observations.

The first assumption was that the entire alerting system needed to be comfortable and fit into the garment used daily by our audience. We did not want to change the routine or add additional devices beyond what they currently use. This decision was made in order to improve user compliance. Another premise was that construction workers should be able to wear the system in several different seasonal conditions. This implies that other clothing could be worn along with the system. Third, we did not want to interfere with the activities performed during the daily duties. For example, workers may carry heavy equipment and other objects, which would press the vest against the person. These conditions limited our design space to the areas which would not interfere with sitting, walking, or carrying things on the shoulder. In addition, we favored mechanisms that would not break if work equipment pressed down on them.

Vest Design

Based on these restrictions, we chose to explore three different modalities for notification: visual-based, auditory-based and tactile-based. These are common among alerting systems, such as smoke alarms, alerts for control systems, and emergency control lights [5, 6]. Vibrating motors were placed around the collar. This place was chosen for convenience of installment and improved likelihood of being noticed. The speakers were placed near the top of the shoulders in order to minimize the distance between them and the person’s ears. The LEDs were placed on the front of the vest. This place was chosen to due to it being in the periphery of the user when the user is looking side-to-side or down. The final design is shown in figure 1 on the next page.

Group Number	Alert	Label
1	Square tone at 490 Hz	Auditory
2	Vibration on back of neck	Haptics1
3	Vibration on front of vest	Haptics2
4	Random LED activation	Visual

This table shows different alerting modalities tested during our experiment.

Figure 1. Finalized vest on a mannequin and on a person.

Evaluation of the Proposed System

We were interested in understanding how the different modalities built into our vest contribute to the user perception of the alerts. The two main questions were:

1. How would each modality compare to each other?
2. How different activities influence the perception of each alert?

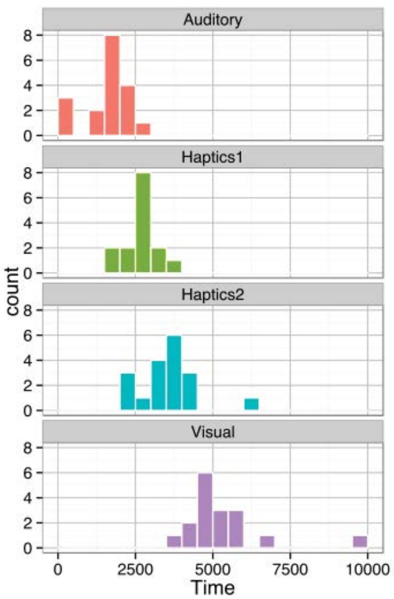
We hypothesized that perception of each modality would be influenced by the activity being performed. Haptics, for example, would not be perceived well during movement. Visual alerts would be missed if the user was looking away from the lights and sounds would be not well perceived during talking. To test this hypothesis we designed an experiment to compare the modalities across different representative tasks.

Study Design

The vest designed can support many different alert patterns by combining different actuators and modulation patterns. Motors can be actuated in different groups, lights and sounds can have different on-off frequencies. To restrict the number of combinations tested, we tested several alternatives to find the ones that would be more likely to give more information about the modalities effect. For the visual alert we choose to turn on LEDs at a random pattern, assuring that at least fifty percent would be on at any moment. For the sound output we choose the frequency that gives the higher intensity possible with our implementation: a 490 Hz square wave. For the haptics we separated the motors into two groups: front of the chest and neck. The vest was equipped with a wrist strap button that could be pressed to acknowledge the alert.

We recruited 24 participants ranging from 18 to 29 years of age, and the average age was 24 years old. Of the participants, eighty-three percent were male and the rest were female. Their weights varied from 112 pounds to 190 pounds. Each participant was assigned to one alert type group, as seen on the right side of the page, and performed three tasks in sequence. Tasks were performed in a lab setting. One participant did not feel well while walking, and his data was excluded.

The first task was a conversation task. In this task participants were standing up and face to face with the experimenter, where the experimenter engaged the participant with questions. The second task was a search task. Participants were instructed to search for an item in a table full of items. In the third task, the participants were requested to walk several times from one point to another inside the lab. They were instructed to press the button as soon as they noticed the alert. The time between the alert activation and the button press were recorded automatically by the computer. Each alert was programmed to fire at a random interval within one minute from the beginning



Time distribution across all tasks for each alert type. The Time axis represents the reaction time of the participants in milliseconds. The Count axis represents the number of participants corresponding with the time average.

of each activity. Unusual circumstances were registered manually by the experimenter.

Results and Conclusions

We ran a two-way analysis of variance (ANOVA) to look for significant effects of modalities and tasks. We found a significant effect of modality on time ($F(3,19)= 28.36$; $p < 0.000001$) and no significant effect of task on time ($F(2,38)= 2.00$; $p = 0.1497$). We also observed a significant two way interaction of task and modality on the response time. The response time distribution shows that participants subjected to the auditory alert tended to respond faster compared to the others, while participants alerted using the visual modality tended to respond slower than the others. Only auditory alerts, on average, grabbed the participants' attention within 2.5 seconds.

Even in the absence of a definitive answer, we have some hypotheses that could explain the observed results. First, the perception of sound and vibration alerts does not change significantly with head orientation. However, the chosen LEDs were directional, which meant the user had to look a certain direction to perceive them. Second, LEDs were not as clearly discernible over the ambient light compared to the auditory signals, which benefited from the quiet environment of the lab. Third, the vibration motors must have a good contact with the body to transmit the vibration. We suspect the difference between the two haptic modalities might be due to a better fit in the body. Walking, for example, did seem to make the haptic perception worse.

From the post experimentation questionnaire, it was found that forty-one percent of the participants felt that the vest was bulky. Approximately seventeen percent of participants wanted a better fitting vest. Approximately eighty-three percent of participants felt that the vest fully or at least closely resembles the normal construction workers' vest. Also, forty-one percent of the participants felt that the vest was not obstructive during any of the tasks. Some interesting suggestions from the participants were using different color LEDs rather than white and having the lights somewhere closer to peripheral vision.

Future work includes a more extensive analysis of the effects observed and refinement of the design. We also intend to conduct experiments modeled after work settings and out-of-the-lab experiments to gather more ecologically valid results.

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