Exploration of Alerting Methods on Vest-Worn Systems

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ABSTRACT

This thesis presents the design and analysis of a vest-worn alerting system with the purpose of warning those who wear it. The goal of this thesis has been shaped around roadside construction workers, people who endeavor to build and maintain the roadways in highly noisy and dangerous environments. Our goal is to determine what type of alerting method best interrupts the worker, allowing him or her to know that danger approaches. Multiple alerting methods will be compared via reaction time and user data derived through critical incidents from the Critical Incident Technique (CIT) and notification-focused questionnaires. All testing is done in a simulated noisy environment. Each of these alerting methods involve combinations of auditory, visual, or haptic components. At the end of this thesis, the different alerting methods will be compared and a mode will be suggested for wearable notification activities. The work proposed in this thesis focuses mostly on vest design and alert testing for construction-based scenarios, but the work can be extended to police and highway worker scenarios.

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Table of Contents

List of Figures

List of Tables

Chapter 1

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 sixty-six percent of roadway work zone fatal occupational injuries in 2013; a pedestrian worker was struck by a vehicle in sixty-nine percent of these transportation incidents. In 2013, sixty-three percent of occupational fatalities in work zones occurred in one of the following occupations: construction laborers, highway maintenance workers, heavy and tractor-trailer truck drivers, first-line supervisors of construction and extraction workers, and construction equipment operators [2].

Due to noise, visual obstruction, mental workload, and environmental conditions, workers have difficulty perceiving approaching cars on a trajectory to strike them. Also, those drivers respond to unexpected highway emergencies in 1.5 seconds, on average, when going 55 mph [3]. While the driver may notice and avoid the worker, the worker may never know that he or she was in danger in the first place. Therefore, warning individuals as early as possible is imperative.

This problem can be broken down into two parts: predicting when to alert the worker and effectively warning the worker. Previous work by Forsyth et al. has shown the feasibility of using dedicated short range communication (DSRC) radios paired with GPS units to accurately estimate the trajectory of cars and warn workers about an imminent collision [4]. Using GPS data from the car and the worker vest, their algorithm could detect and deliver appropriate warnings 6 – 7 seconds away from the vest, enough time for both the car driver and the roadside worker to avoid an accident [4]. The next step beyond Forsyth et al.'s work is to create the base design for such a GPS-based collision trajectory system. This base design is the main focus of this thesis and will be tested through two separate studies.

1.1 Design Space

Roadside construction workers are required by OSHA to wear helmets and high-visibility safety apparel for protective purposes while working near heavy equipment or near hazardous situations, such as near busy highways [5]. The helmet was used for protective purposes, especially from falling debris. The vest was used for visibility purposes. Other safety research work has used the helmet for alerting purposes due to its ability to place alerting devices near the person's visual periphery and ears [6]. However, the vest, which was supposed to be the high visibility safety equipment, was rarely used for alerting purposes. Therefore, the vest was chosen over the helmet for two reasons:

1. We are intending for the alerting system to have high visibility not just for the worker but for other workers and drivers around him [7], and
2. The vest was known to be worn in a standard way [7].

A significant cause of worker deaths was unawareness from both the worker and the vehicle drivers. Almost all cases cited by the National Institute for Occupational Safety and Health (NIOSH) Fatality Assessment and Control Evaluation (FACE) reported highway work zone cases involving laborers being backed over, run over, and otherwise struck by vehicles [8] [9]. The victim was almost always facing away from the vehicle and was unaware of the danger he or she was in due to environmental noise [9]. Increasing danger awareness was important for both the worker and the driver, and the vest was the largest safety article that workers are required to wear.

The second reason for choosing the vest as the design platform was because there has been a trend over the past ten years where construction helmets are improperly worn with the with the helmet bill facing behind the worker's head [10]. Workers wear helmets the improper way for vision-based and social reasons [10]. Vests are normally either worn zipped or unzipped. The vest remains on the person's shoulder and around his or her neck. This trend gives us a stable place to test alerts on.

1.2 Research Focus

The main goal of the research presented in this thesis is to increase personal danger awareness using current visibility-based clothing, also known as the construction vest. With these thoughts in mind, we will examine three questions throughout this thesis:

1. Where are the stable and consistently effective alerting zones on the construction vest?
2. What alerting modalities are most effective on a vest?
3. How do the different alerting methods interact with each other?

The first question examines how the design of the vest should be shaped and executed. Three different alerting parts will be examined through the work. The alerting methods can include visual, tactile, and audio elements. The second question will explore how effective each of the alerting methods are on a vest. This part will look into how effective each of the methods are on the vest, where effectiveness is measured in terms of reaction times and user perceptions. The third question looks into how combinations of alerting methods interact. We want to know whether the alerting methods support, or detract, from each other when the multiple alert methods are combined together.

1.3 Contributions

The work contained within the thesis presents the design and analysis of a vest-worn alerting system with the purpose of warning those who wear it. The context for this work revolves around emergency situations, where the person who wearing the vest may not know of his or her danger and has little time to reach safety. The thesis will present and provide a design rationale for a vest-based alerting system and the study design for testing such a system. Multiple alerting methods will be compared via reaction time and user perception data derived through notification-focused questionnaires, critical incidents from the Critical Incident Technique (CIT), and observations. At the end of this work, we will suggest at least one alerting mode for roadside construction applications. The work proposed here focuses mostly on vest design and alert testing, but the work can be extended into many different fields, such as highway workers and police officers.

1.4 Paper Organization

The following chapters will outline the design of the alerting vest and the studies performed to test the efficacy of the design. Chapter 2 provides a brief background on previous work in the area of notification technologies and construction safety. Chapter 3 presents the two vest designs and the prevailing design rationale employed throughout this research. Chapter 4 describes the studies crafted to test the efficacy of the vest design concept. Chapter 5 presents the results of the preliminary and feasibility studies. Finally, Chapter 6 concludes the work and presents possible directions this work can take in the future.

Chapter 2

Background

In this chapter, we will investigate current technologies used to notify people as a starting point to understand how to better notify construction workers. Next, we will discuss current alerting options for construction based scenarios. The background presented in this chapter forms the basis for why the alerting methods were chosen, what other solutions are out there for construction workers, and how the system presented in this thesis was different from the other work.

2.1 Common Notification Technologies Used Today

One of the first visions of wearable technology was that it could be a personal assistant to the user. It would know when, and when not to interrupt the user because it "just knew" what a user's preferences and habits were [11]. The wearable system, which could range from a watch to a vest to beyond, would understand environmental context and decide the appropriate level of user involvement. A question appeared during this time: how should we notify people? One answer was to interrupt them and catch their attention.

Interruption analysis, and thus notification design, has been formalized and discussed in both Chewar and Witt's work. Chewar created an interruption, reaction, and comprehension (IRC) framework for qualitatively sorting notifications into categories based on the amount a person was interrupted, how much they need to react, and how much they need to comprehend the notification [12]. Witt focused more on creating an approach for developing wearable interfaces, specifically with interruption management [13].

Based on Chewar's framework, interruption focused on distracting the user from his or her primary task [12]. Reaction focused on making the user perform a predefined action [12]. The predefined action can be as complex as performing a dance to initiate a program to as simple as stepping away from a place. Comprehension focused on the user understanding more because of the notification [12]. An example of comprehension was ambient media.

Alongside this work, Witt expounded on two concepts: the difference between primary and secondary tasks and the importance of noticing the secondary task while performing the primary task [13] [14]. The primary task was what a person was doing before the notification, and the secondary task was what the notification was trying to get the person to do. From there, the alert was grouped into two categories: immediate and not immediate [13] [14]. Non-immediate alerts are meant for users in work environments where multiple devices are competing for the user's attention. Immediate alerts are meant for emergency related situations.

Notifications during emergency situations, such as when a roadside worker is in danger, fall into the category of high interruption and reaction notifications. This framework meant interruption, and thus a reaction to that interruption, were important for the situation described in this thesis. The notification technology needed to be easily recognizable as an alert. Also, we wanted the alerted people to respond without any options for negotiation. While we cannot force such an event to happen, we can encourage it through the design of the notification.

The next important part of the notification was the elements that make up the notification. According to literature, these elements were auditory, haptic, and visual-based. Auditory signals were expected to be the most direct, the most imperative at getting a person's attention [14] [15]. An auditory alert has been the default choice for alerting systems for many different notification technologies, such as the SmartHat [15]. Haptic signals have been viewed as a more discreet version of auditory signals, where the alert was more personalized and private [16]. While they are not as consistently effective as auditory alerts, they have become a common alert option for today's cellphone notifications. The final common notification method was through lights, specifically flashing lights. Flashing lights were present on most head-worn and some wrist-worn alerting systems [14] [16].

2.2 Safety-based Notification Technologies

Along with selecting the design space, and the alerting methods to install in the design space, another objective of this work was to provide workers with a wearable protection system, especially for potentially hazardous situations such as busy streets or in construction scenarios. Handheld and wearable devices can take a step to protect the user in dangerous situations, such as the user running into objects and cars. The next two subsections cover what types of technology were currently available for proximity and safety awareness.

2.2.1 Safety and Proximity Awareness in Dangerous Situations

Three examples were considered pertinent to roadside safety applications. The first work was performed by Powale about roadside safety for law enforcement and emergency personnel. The second work was the SmartHat, led by Teizer, which looked into making a battery-less proximity detection system for construction workers who completed activities near heavy machinery. Finally, the third work, completed by Castro et al., involved creating a predictive neural network derived model to help improve worker safety.

Powale performed research on improving the safety of law enforcement individuals and emergency personnel who are stopped on the side of the road in poorly lit conditions [17]. Alerting methods explored included haptics on the waist and wrist and sirens either on the vest or from the car. Most of the predictive processing was intended to be housed in the vehicle [17]. Powale's thesis was interested in seeing how well haptic and auditory signals alerted police officers in low and high auditory noise environments. Auditory noise was set, at max, to 80 dB [17]. Auditory alerts were perceived first in Powale's, but haptic proved more salient in high auditory noise environments. A question arose in Powale's work, but was not answered, of whether auditory signals could truly be better at alerting people or they could be ingrained as an alert within people's mental psyches.

Unlike the area Powale was interested in, current wearable construction alerting technologies revolve around proximity alerting systems and tagging workers and equipment in a construction work environment. An example system placed transmitters on the heavy machinery and receivers in worker's helmets [15]. This project was called SmartHat. The testing scenario was based in hazardous regions within construction sites where workers may, or may not be able to tell where heavy machinery was going. The alerting mechanism was a piezo alerting mechanism placed on the bill of the construction hat [15].

A similar system, created by Castro et al., involves tagging workers, predicting where they will go, and alerting the work region that an accident may happen. The workers wear passive RFID tags within their vests, and the data was filtered to the person managing the construction situation [18]. The authors used neural networks for their predictive methods. Vests were used in [18] because vests are required in environments where construction workers worked near heavy equipment and workers have been known to wear helmets inappropriately [10] [19].

2.3 Insights Found and Research Direction

Both of the systems mentioned in [15] and [19] rely on auditory alerts to notify workers of impending danger. However, as discussed before, auditory alerting methods are not the only available option for alerting systems. Both of the construction focused notification systems have been reliable at issuing alerts, but there was no data on how well the alerts were heard over the other noise. However, as stated earlier, multiple ways exist to notify people that may, or may not, involve auditory alerts.

The wearable construction safety area has more be explored. In this thesis, we will determine the feasibility and capability of placing haptic, auditory, and visual alerts on a vest-worn alerting system. For this work, the vest was chosen over the helmet, because the vest was meant to increase visibility within the work environment [7]. Every worker was expected to wear such vests in environments near roads or around heavy machinery [5] [7]. Chapter 3, Problem Description and Vest Design, will cover the details of the construction vest's design. Chapter 4, Proposed Studies for Testing the Vest Design, will explain the studies used to test the system design.

Chapter 3

Problem Description and Vest Design

In this chapter, we will state the problem space examined in this thesis, discuss the overall design of the vest, and explore two different implementations for the vest. Most of the work presented in this thesis seeks to utilize the area on and around the should as a space for alerting the worker in case of danger. This vest can be programmed with different alerting patterns to keep roadside workers safe from moving machinery and passing vehicles around the work site.

3.1 Problem Space

Roadside construction workers are required by OSHA to wear helmets and high-visibility safety apparel for protective purposes while working near heavy equipment or near hazardous situations, such as near busy highways [5]. The vest was chosen instead of the helmet because (1) we intend for the alerting system to have high visibility not just for the worker, but for others around him, and (2) the vest was known to be worn one way [7].

A significant cause of accidents in roadside work was traffic control supervisors not wearing the appropriate equipment and apparel in the first place [8] [9]. The victim was temporarily reassigned to a place where they did not normally work, which means that they are not wearing the appropriate visibility apparel during the substitution [8]. However, the work presented here does not seek to provide a solution for the situation where workers are suddenly assigned to different areas within a construction environment. We focused on the cases where a worker was assigned to the area he or she was trained and prepared to perform.

3.2 General Vest Design

Once the design space was chosen, the next part of creating the alerting system involved planning where the alerting mechanics would be placed upon the vest. The placement of an actuation mechanism can make a difference in the effectiveness of the alerts. Auditory sound quality and signal strength were affected by distance. The sound level decreases by approximately 6 dB for every doubling of the distance between the speaker and the ear [20]. Therefore, the speakers needed to be as close to the ear as possible, hence the placement of the speakers.

The mindset behind the visual alert was similar to the auditory alert. Effective light intensity decreases exponentially as the distance between the light source and receiver increases [21]. The difference between light and audio signals was that light signals do not diffuse in the same way as audio signals do. The light receiver, which was the vest wearer's eyes, may not receive, or see, the light alert depending on which way the wearer was looking [22]. Therefore, the visual alerting signal needed to be as close as possible to the wearer's eyes while also remaining on the construction vest.

Tactile perception was still a relatively unknown field of work. Most of the work for tactile perception has centered on non-hairy human skin, such as hands and wrists [23]. Hairy skin, such as arms and chests, react to tactile sensations differently compared to non-hairy skin, but little else was known besides the two categories of skin handle tactile perception differently [23]. According to [23], [24], and [25], stationary places on the human body with little to no hairy skin would be advantageous for tactile signals. Stationary places are places where the clothing and the skin underneath the clothing do not move much with respect to each other. Non-hairy, stable places on the human body include the shoulders and neck area on the construction vest.

Table 3.1. Summary of guidelines for each of the alerting methods.

Modality	Key Design Points
Auditory	- Should be close to ears - Changes in tone
Haptic	- Should be stable - Neck and shoulder blades
Visual	- Should be close to eyes - Peripheral vision

Figure 3.1. Diagram showing general placement of alerts.

The high-level conceptual drawing of placement regions was shown in Figure 3.1, as shown above. Each of the alert placements was chosen using the requirements shown in Table 3.1 as a guide. The yellow area corresponds to the location of the visual alert. The black area corresponds with the auditory alert. The green and blue areas correspond with the haptic alert. An important part of creating the alerting vest was to ensure that all alerting mechanisms did not harm participants. The audio signals had to be less than 100 dB to fall within the IRB restrictions. A speaker with a maximum decibel rating of 80 dB was selected for prototyping purposes. For noise and alert purposes, 80 dB was chosen as the upper limit because of the desire to simulate scenarios relatively close to real construction zones. While heavy equipment in construction zones can create about 120 dB of noise pollution, 85 dB was considered the limit before safety protocols require hearing protection [26]. To protect participants during the feasibility studies, lower noise and alert strengths were used. The hypothesis was that as long as the signal to noise ratio stays the same, the results from the lower signal strengths apply to louder scenarios [27].

The visual alert proved to be more difficult to implement. Peripheral vision has proven to be useful for alerting purposes since humans are sensitive to sudden changes in their periphery [22]. However, this means that the person being alerted has to at least see the visual alert to notice it. Many participants stated they were not able to see the lights while looking directly forward or upwards. These tests showed internal changes would need to be implemented on the vest, such as a mechanism that forced the lights into the periphery, to ensure a person could see the visual alert while he or she was looking forward. To improve odds for alerting the wearers, the lights were set to be at maximum brightness, which made it dangerous for people to look directly at the lights for longer than a few minutes [28]. Since the alert was expected to last up to a minute, the visual alert should not cause severe damage to people looking directly at the LEDs.

The general area for the vibrating motors was chosen because shoulder and neck area was considered a low movement area, allowing for vibration motors to be placed and to keep a consistent connection with the wearer's skin [24] [25]. The choice for haptic placement depended on which part of the body was accessible via the vest and was also sensitive to the tactile alert. It was found from initial testing that the area near the collarbone and shoulder blades were the most sensitive to changes in tactile sensations among the regions around the neck and chest region [29].

However, they were comparatively insensitive to sensations compared to finger and wrist area [23] [29].

3.3 Preliminary Study Vest

With the concepts derived in Section 3.2 in mind, the first vest was created. The overall hardware sub-system for the first vest prototype, represented in Figure 3.2 and implemented in Figure 3.3, consists of twenty-four LEDs for visual alert, two speakers for the auditory alert, and six vibration motors as a part of the haptic alerting mechanism.

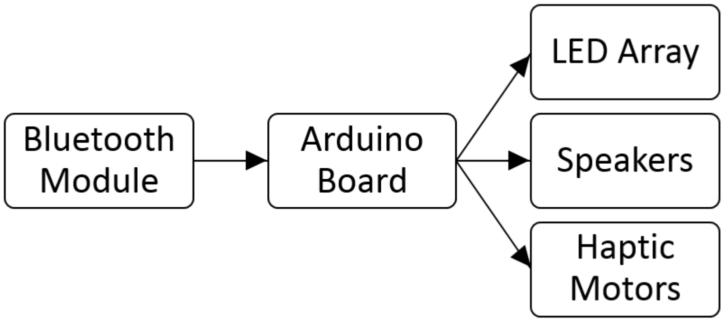

Figure 3.2. Visual description of how the alerts were sent to the vest.

Figure 3.3. Finalized vest created for preliminary studies. This vest was used for initial and preliminary tests, which informed the design for the second construction vest.

Some of the circuit designs were based on [30] and [31]. [30] was a schematic for attaching an Arduino board to Bluetooth, and [31] was a schematic of a driver for the haptic part of the system. The alerting system was controlled with an Arduino Mega controller. The alerting vest's signal flow was shown in Figure 3.2. The controller could accommodate twenty-four LEDs independently and had sufficient pulse-width modulation (PWM) pins for vibration motor control. The Arduino Uno and Duemilanovae controllers were also examined since they were physically smaller than the Arduino Mega; however, they had fewer digital pins to control the LEDs. Since different visual patterns were being experimented with an individual control to each LED was necessary for this vest. The connection and system flow concept were kept modular for debugging purposes while the vest was being created and alerting modalities were being chosen. Each of the different alerts used for the preliminary study was listed in Table 3.2.

Table 3.2. Description of the different alerts installed in the vest. The group number corresponds with the label used when taking data.

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

The preliminary vest was tested using the study described in Section 4.1. The results can be found in Section 5.1. During initial testing, multiple issues were found in the preliminary design. The visual and vibration alerts were not easily seen or felt when a person was wearing the vest. Also, people stated that lights were ineffective when they were focused on a specific task, such as searching for an object on a table. Other users noted the vibrating motors could not be felt through clothing heavier than a light sweater. An issue noticed during testing was that the vibrating motor could irritate the area around the collarbone if it was left on for too long, which was about one hour. Only users who performed the first tests, where the vibrating motor could be left on for multiple minutes, complained about the irritation. However, this issue could be a problem if this system experiences multiple false positives once implemented as a full system.

3.4 Feasibility Study Vest

After the preliminary test, the first prototype was retired. The vest proved to consume too much time for debugging purposes due to the implementation decisions made to craft the system. One such problematic decision was how the LEDs were implemented. They were installed too close to each other. Also, the drivers for the haptic motors did not handle donning and doffing of the vest very well, causing them to become unusable after testing. The vest needed to be changed and updated, and those changes can be seen in Table 3.3. The second vest can be seen in Figure 3.4 on the next page.

Table 3.3. Updates to the vest design.

Alert	Original	Update
Auditory	Beeping	- Siren-like signal alternating with a beep - Adjusted frequency
Haptic	On-off (front or back of collar)	- On-to-Off on both front and back of collar
Visual	Random LED activation	- On-to-Off of sides of vest - Increased LED area

The vest used for the feasibility study was lighter and easier to adjust physically compared to the first vest. It could be reshaped into the major clothing sizes with very little effort through the use of Velcro and snaps. The vest could be refitted to Men’s Small, Medium, and Large sizes. Most of the power control and processing was removed from the vest and placed onto, or next to, the Arduino Mega. The removal of excess circuitry made the vest easier to repair throughout the feasibility study. The alerts were programmed similarly to the first vest, but the alerts themselves were changed. Table 3.4, shown in the next page, lists and describes all of the alerts implemented on this vest.

Figure 3.4. The vest used for the second set of studies. The left picture shows the vest, while the right picture shows each of the modalities.

Table 3.4. Description of the alerts for the feasibility study vest.

Alert Method	Alert Implementation
Auditory	Sine wave from 2.5 kHz to 3.5 kHz followed by a 3 kHz beep from both speakers
Visual	Sawtooth waveform ranging from maximum to minimum light strength followed by both LED sets blinking once
Haptic	Sawtooth waveform ranging from maximum to minimum vibration strength

The auditory alert circuitry and positions remained similar to the first vest. The main changes were the types of speakers used, the auditory alert used, and how the speakers were placed onto the vest. For the first vest, the auditory alert consisted of constant beeping. The speakers chosen for this vest could achieve a more consistent volume across a wider range of frequencies compared to the first choice of speakers. After the speaker set had been chosen, the auditory signal was changed to a mix between a beep at 3 kHz and a ramp signal going from 2.5 kHz to 4 kHz. This frequency range was chosen to ensure that the auditory signal remained in the audible range for construction workers while also allowing for the auditory alert to retain siren-like qualities, such sudden frequency changes [32]. The speakers were fashioned into buttons to make removal and repair easier.

The LEDs were also changed in the vest used for the feasibility study. They were divided into two groups, left and right, instead of being individual elements. Participants in the preliminary study could notice when the light was on or off, but not any specific patterns on the vest. The first LED design restricted the number of LEDs that could be placed onto the vest. The second design involved dividing the LED's into two regions, which increased the maximum number LEDs on the vest, but reduced the ability for the vest to have a variety of patterns. During design testing for the second vest, the lights covered more visual area compared to the previous vest. Participants who helped in both the preliminary and feasibility study noted that they saw the alert more often with the new design than before in the preliminary design.

The vibrating motors were changed to coin type vibrating motors. The previous haptic motors took more effort to keep safe and intact during the donning and doffing stage of the studies. The coin-type motors proved to be cheaper, easier to sew into the fabric, consisted of few points of failure, and easier to find commercially. The tradeoff between two previous and the current motor was the change in the feedback sensation. The feedback present with the coin-type motor felt similar to cell-phones buzzing, whereas the feedback present within the previous vibrotactile motor felt very different. The vibration pattern was formalized into a sawtooth waveform in the second vest. The first vest was supposed to use a similar pattern, but the alerting pattern felt more similar to an on-off sensation rather than a sawtooth waveform. Participants used in both studies thought that while the first vibration motor felt distinct from other devices compared to the second motor. However, they immediately recognized the vibration patterns from the second motor as an alert. The upcoming chapter will describe the tests performed on the vest designs. Both of these prototypes will be examined and the insights will be summarized in the Conclusion of this thesis.

Chapter 4

Proposed Studies

This chapter will describe the studies performed to analyze the effectiveness of alerting methods on roadside worker vests. These studies were designed in order to answer the second two questions posited in the Introduction:

- What alerting modalities are most effective on a vest?
- How do the different alerting methods interact with each other?

In these studies, alert interruption and reaction were more important compared to understanding and comprehending the meaning behind the alert. We wanted to know whether a person would be interrupted from their current work and react quickly when alerted. The preliminary study will examine the first foray of using the proposed vest design. During the test, each of the individual alerting methods will be examined. The feasibility study will use the knowledge derived in the preliminary study and examine the combinations of alerting methods. The results from each of these studies will be presented and examined in Chapter 5, Results.

4.1 Preliminary Study Design

The preliminary study was created to gather initial data about how each alerting method behaved on the vest, specifically when interrupting a participant working. The vest used for this study was the earlier prototype described in Section 3.3. The preliminary study was designed and executed with assistance from Wallace Lages and Namitha Somasundarum [33].

4.1.1 Description of Metrics

The metrics used for the preliminary study were response time and impressions of the effectiveness of the vest. The response time was derived using a wrist-worn acknowledge button. An alert would be randomly sent to the participant. Once the alert was started, a timer would initiate. The participant stopped the timer, and the alert, by pressing the acknowledge button. The elapsed time was collected on a host computer to be statistical purposes. The impressions gathered by the questionnaire, which was modeled after customer satisfaction surveys, included whether people thought that the vest seemed like a vest and whether the alerts were perceived as alerts. The information for the questionnaire was meant to guide future iterations of the construction vest.

4.1.2 Study Outline

The participants were divided into four groups: Auditory, Haptics1, Haptics2, and Visual. The Auditory group was alerted using a beeping tone similar to back-up alarms. The Haptic1 group was alerting by the vibrating motors on the back of the neck. The Haptic2 group was alerted using the vibrating motors on the front of the neck. The Visual group was alerted using a shimmering pattern where the lights start from one side and end on the other. Descriptions of the alert implementations can be found in Section 3.3.

Each participant from each group performed three activities: talk to the experimenter, search for a specific object on the table, and walk around a lab environment. These activities were generalizations of the activities that constructions workers performed [34]. The participants were issued an alert randomly between 30 seconds to 1 minute by their designated alert. This alert would continue until the participant acknowledged that the alert occurred.

When alerted, participants were to stop their primary task and press a wrist-worn acknowledge button. Afterward, the participants completed a survey to gain their impressions of the vest. The results can be found in Section 5.1. This study was meant to be informative about the baseline trends for how people reacted to each kind of alert.

4.1.3 Setup Limitations

Multiple limitations existed for the preliminary study. First, the participants were not of the intended audience, roadside construction workers. This is because we were looking to see how the alerting methods affected people in general, not just construction workers. We believed the results from this study would still be applicable for the case of construction workers. The next limitation was the tasks offered for the participants. The tasks were roughly modeled after activities construction workers performed in that they were physical and required their attention. To make the tasks closer to construction work, we would need to involve artifacts and other physical devices for the participants to manipulate. The third limitation was the frequency of alerts paired with training expectations. In real-life situations, workers should be alerted infrequently. Also, they would not be alerted soon after being trained. However, we did not have the time or the willing participants to see how well participants could comprehend alerts after months of not being alerted. These limitations will still exist in the feasibility study, and they will be further examined in Section 4.2.3.

Along with the stated three limitations, there existed two main physical limitations to this study: the chosen testing area and the bias introduced by the acknowledge button. The chosen testing space was not equally noisy among the different alerts. Visual and haptic noise were much higher compared to auditory noise. The testing area was quiet and brightly lit. In addition, no data was taken to account for different response times for pressing the acknowledge button. There was an assumption that all participants would press the button as quickly as possible. The time taken to press the button would be approximately the same no matter where his or her hands were during the activity. Bias would be introduced into the data, but the trends of which alert happened first would be kept intact. To improve results, the participants were instructed to press the button as quickly as possible.

4.2 Feasibility Study Description

The goal of this feasibility study was to observe how the user responds to alerting method combinations in an audibly, visually, and haptically difficult environment. This study took the second prototype, improved based on feedback and results from the preliminary study. The study environment was manipulated so that the background noise could simulate a similar environment to what roadside workers face. We wanted the study environment to be similar to construction scenarios, not replicate, due to safety reasons and study limitations. The limitations will be explained later in this section.

4.2.1 Description of Metrics

The metrics used for this study are response time and qualitative data meant to gather impressions about the effectiveness of the alerts. The reaction times and task completion times, which measure how fast people respond to an alert given the alert is issued when it is supposed to, form the quantitative foundation used to find statistical significance between each of the test scenarios. Detection time (how long does it take to notice an alert), error rate (how often does the participant notice or miss the alert by mistake), and false alarm rate (how often is the alert issued inappropriately) were other quantitative metrics used for interruption analysis [35] [36]. Reaction and secondary task comprehension times were chosen over the other metrics because (1) detection time was used in situations where the alert was issued once instead of repeatedly, (2) there was only one alert combination that participants needed to pay attention to, and (3) we were interested in cases where the alert is always issued when it was supposed to be issued.

Reaction and task completion time are gathered using video recordings. The participants are asked to raise their hands as soon as they received an alert. The time between when the alert was issued and when the person acknowledged the alert was recorded using the video data. Reaction time was measured as when the participant noticed and started to raise his or her hands. Task completion time was measured as the time it took from when the alert was issued until when the participant finished raising his or her hands. Secondary task completion time was important because it showed how quickly people reacted and completed the secondary task. This is analogous for when a person needs to do a simple action to reach safety.

The qualitative data was derived from a questionnaire used throughout the feasibility study and observations captured by the researcher. The questionnaire was modeled using notification based surveys and guidelines derived from Chewar's work and customer service and product review surveys [12] [37]. Two additional evaluations could have been used for this study. They included Horvitz's Interruption Workbench and the Self Evaluation of Anxiety (STAI) questionnaire. The first evaluation method examined interruption cost for a user when he or she is handling multiple streams of tasks [38]. The second evaluation method measured how much a person's anxiety level changed during the study [39]. These methods would be more appropriate for user studies that involve the prediction work performed by Forsyth et al. and the target audience. Also, Horvitz's Interruption Workbench has normally been substituted with interruption-focused questionnaires, such as the one used in this study, due to data processing overhead reasons [12].

The qualitative data was split into two groups: information derived from user impressions and information derived from users answers to which alerting method worked better compared to others. The user impressions were derived from informal interviews and researcher observations and were coded and analyzed using open-coding and thematic analysis [40] [41]. Qualitative events observed by the researcher are analyzed using the critical analysis technique (CIT) [42]. CIT was chosen over a method such as heuristic analysis because CIT excelled in situations where people interact with devices and parts of a system [43]. CIT was meant to capture people's positive and negative reactions to a system so that researchers can learn of the benefits, and weaknesses, of their work. Heuristic analysis was more useful for situations where a whole system is involved, not just a part of the system. The answers to pertinent alerting methods are analyzed using statistical methods.

4.2.2 Study Outline

Before the experiment, the participant takes a questionnaire to collect physiological data and to determine what impairments he or she might have. After the questionnaire, the participant dons the alerting vest. The participant was given a training session where he or she was issued the alert multiple times. He or she must acknowledge the alert by raising his or her arms. The training session continues until the participant was comfortable with the alert and the acknowledge action. Once the training session was over, the environmental noise was increased through artificial sources.

The environmental noise consisted of three elements: visual, haptic, and auditory. Visual noise can be two or more light sources blinking at differing frequencies. Some of the noise was intentional, such as slowly changing lights on the table where people performed the assigned tasks, point source lights that turned off and on randomly throughout the session, and slowly flickering overhead lights within the test room. The haptic noise was interference created by walking, which caused the vest to shift, and the bass from the auditory noise. The auditory noise was derived from a recording of construction noises. All of these noise sources were created using either natural phenomenon (walking and overhead light flicker) or from freeware sources (such as freely available Arduino code and sound recordings).

The different tasks that the participants will perform can be categorized into mental, verbal, visual, and movement tasks [14] [44] [45]. Mental tasks require observing and processing the information to complete it. Verbal tasks require the participant to speak and listen to someone else. Visual tasks involve the participant relying on his or her visual abilities to complete the task, such as searching for different pieces of a puzzle. Movement tasks involve full body movement, such as moving objects from one end of the room to another.

In this situation, participants are tasked with a primary and a secondary task, similar to the situation described in [45]. The primary task would be one of a set number of tasks that the worker could be working on. Possible tasks would fall into six categories: build, organize, disassemble, transport, maintain, and converse. An example of how the test set up looked like can be seen in Figure 4.1 as shown on the next page. Each of these activities involved qualities of at least one of the four class types mentioned in the previous paragraph. These categories were chosen based on the types of tasks roadside workers are expected to perform [34]. The tasks include:

1. Build a physical puzzle using either poker chips or JENGA blocks (build),
2. Sort numbered and differently colored cards numerically and by color (organize),
3. Take apart the previously built puzzle slowly and carefully (disassemble),
4. Carry a box from one side of the room to the other (transport),
5. Repair the disassembled puzzle to its previous stature (maintain), and
6. Talk with the moderator (converse).

The secondary task requires the participant to stop the current task when alerted and to respond appropriately. In this case, the appropriate response was for the participant to raise his or her hands as soon as the alert was received. Once the secondary task was finished, the alert was stopped, and the participant was asked to fill out a short survey before continuing onto the next task. At the end of the session, the participant will complete a final survey to measure qualitative impressions about the alerts themselves instead of the vest, unlike the initial study.

Figure 4.1. Test setup with the Build task completed.

For this environment, the auditory noise level was kept around 70 dB average. The peak level was around 80 dB, and the minimum was approximately 30 dB. The audio recordings included noise within construction environments, such as loud beeps (back-up alerts), sharp hammering noises (drills and jackhammers), and machine monotone (engine noise) [26]. The level of auditory noise pollution was reduced by 30 dB to keep the participants safe from harmful noise exposure. Appropriate hearing protection can be given to reduce auditory noise down to below 80 dB [46].

The haptic and light noise pollution are not formally measured, but they were deemed to be safe enough for the users not to worry about any extra protection. The types of visual noise emulated in this study included bright overhead light (similar to spotlights or the sunlight) and flashing lights (similar to indicators that show a device was properly working) [26]. The types of haptic noise simulated in the experiment included heavy shaking (bass from drilling and jackhammer recordings), carrying objects (boxes and other equipment), and walking [26].

Out of concern for the participants' safety, the auditory alerting signal ranges between 65 to 75 dB, with the signal starting louder and changing frequency from 2.5 kHz to 4 kHz, with the average frequency being around 3 kHz. The light signal was set to maximum power, which means that the user cannot look at the light signal for more than a minute without causing retina damage. The haptic alerting signal was set to its maximum power, but it could desensitize the user after ten minutes. Results from the feasibility study can be found in Sections 5.2.

4.2.3 Setup Limitations

Similar to the preliminary study, multiple limitations existed for the feasibility study. The first three limitations were similar to the limitations found in the preliminary study. The final one, which referred to the simulated noise, was important to this study more than the preliminary study. The first limitation of this study was the tasks offered for the participants. The tasks were modeled after activities construction workers performed. The task list was derived from the US Bureau of Labor [1]. The common thread among all of the tasks was that they were physical and required participants' attention. To make the tasks closer to construction work, we involved artifacts and other physical devices for the participants to manipulate. However, these tasks were not completely accurate representations of construction work, and they will never be compared to working at a construction worksite. A list of tasks cannot account for all of the different work and situations workers are in each day. For this study, that was an acceptable limitation, because we wanted to know how the alerts affected people, not just construction workers.

The second limitation was the frequency of alerts paired with training expectations. In real-life situations, workers should be alerted infrequently. In the best-case scenario, they will never be alerted. This means workers will rarely be alerted soon after training. Just like with the preliminary study, we did not have the time or the willing participants to see how well participants could comprehend alerts after months of not being alerted. This would need to be work done in the future.

The third limitation of this study was the pool of participants. Since the research presented was a feasibility study, most of the participants came from the Sona, a cloud-based participation service implemented by the Virginia Tech Psychology Department. Those students consisted primarily of Introduction to Psychology students. Most of these students are undergraduates within the ages of 18 to 22 years old. Their age means that that they are more likely to be able to handle more auditory frequencies compared to older people, especially construction workers. According to [47], construction workers tend to be approximately 44 years old. Approximately sixty-one percent of these construction workers have slight to moderate hearing loss, which effects the hearing range frequencies above 4 kHz [47]. While the signals used for interruption purposes remained between 2 kHz to 4 kHz, the participants still had higher dynamic hearing range than the intended audience.

The final limitation was that the test environment was a simulation of the noisy environment found at roadside construction sites. This simulation accounted for some of the noise sources found within construction environments, but not all. Additional environmental conditions not accounted for include sunny times and night time, also known as light intensity variation, and localized audio-haptic noise, such as jackhammers and other drilling tools.

Chapter 5

Results and Discussion

This chapter will cover the results derived from the preliminary and feasibility studies described in Sections 4.1 and 4.2. The results from the original preliminary study, which was described in Section 4.2, will be discussed briefly before the results from the feasibility study. These results are described because they guided the design for the prototype used for the feasibility study and to give the readers an idea of possible response times to each one of the different alerting methods. After the results are presented, they will be discussed in Section 5.3.

5.1 Individual Alerting Methods and the Preliminary Study Limitations

For the preliminary study, alerting modality, activity type, and response time were analyzed using a two-way analysis of variance (ANOVA) to determine how much of an effect the alerting modality and activity type had on response time. A significant effect of modality was found on time ($F(3,19)= 28.36$; $p < 0.000001$) while no significant effect was found for task on time ($F(2,38)= 2.00$; $p = 0.1497$). A significant two-way interaction was observed between the 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. The response distributions can be seen in Figure 5.1.

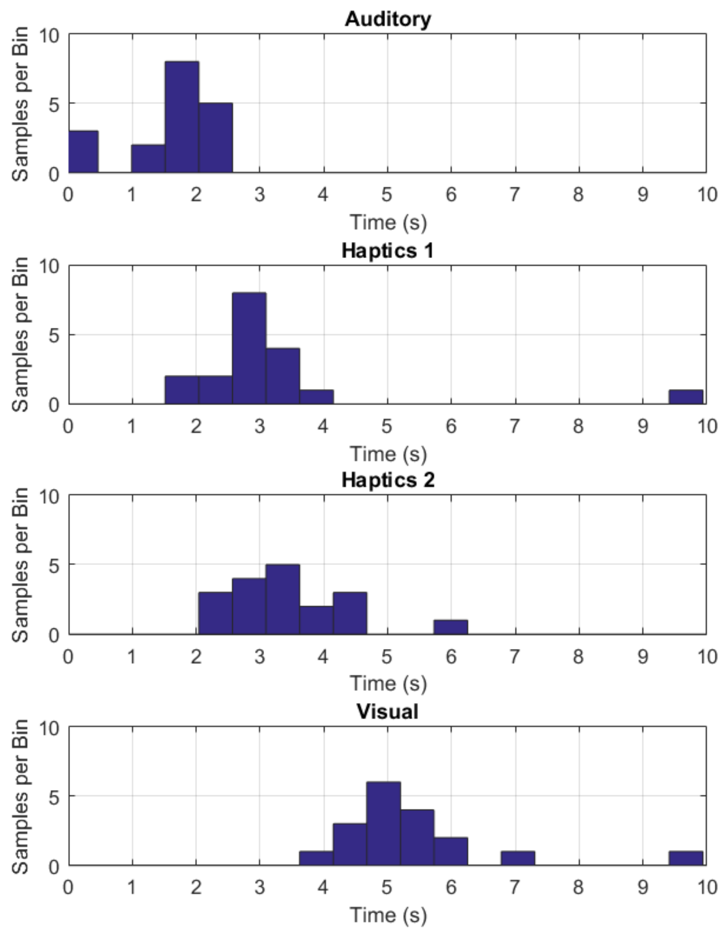

Figure 5.1. Cumulative responses across all tasks for the preliminary study.

While analyzing the behavior of the participants, a few insights were found. First, the perception of sound and vibration alerts did 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. The difference between the two haptic modalities might be due to a better fit in the body. Walking, for example, seemed 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. The different colored LEDs were not implemented in the feasibility study, but the insight should be noted for other work.

In this study, we found the audio alert to be the most effective of the four different alerting methods. The haptic methods were very similar to each other regarding user perceptions and response time, and the two haptic methods should be combined with each other. The visual alerting method needed to be reworked. The alert was in danger of not being seen by participants. Therefore, the alerting method was revisited and changed for the feasibility study. The changes were noted in Section 3.4. These insights guided the research for the feasibility study.

5.2 Analysis of Alert Combinations

To improve response times, the different alerting methods were combined in various ways. For this part, the two haptic alerting methods were combined into one haptic alerting method. The alerting methods used were auditory-haptic-visual (AHV), haptic-visual (VH), and auditory-visual (AV). Each of the alerting methods was chosen based on feedback from the preliminary study and from volunteers who to tested the feasibility study. The auditory-haptic alert was not examined because the alerting method was deemed too similar to the AV method.

A training session was performed before each testing session. The participants were introduced to the alert and the secondary task, raising their hands, multiple times before testing would begin. The training session allowed for the participants to become acquainted with the alert, reducing learning bias. The training session was extended if a participant was having difficulty recognizing an alert. After the training session, the participants were asked to perform six different tasks modeled after activities roadside construction workers perform. Once participants were alerted, they were instructed to stop their current task and raise their arms. The primary task was the original task the participant was tasked with. For the case of the feasibility study, these tasks include Build, Organize, Disassemble, Transport, Maintain, and Converse.

The secondary task was the task that they must perform when they are alerted. The participant was to raise his or her hands after being alerted. The secondary task was considered complete when the participant had fully stopped the primary task and was standing with hands raised. The same alert was issued to the participant at random times. After the secondary task was completed, the current primary task was considered complete, and the participant was asked to answer a few survey questions.

The quantitative data was collected via videotape. The reaction time was measured from when the alert started to when the person started raising his or her arms. The task completion time was measured from when the alert started to when the participant finished raising his or her arms. More information can be found in Chapter 4, Proposed Studies. For each combination, the response times and qualitative results will be shown and discussed.

5.2.1 Auditory-Haptic-Visual Alert Combination

The AVH alerting combination employed all three different alerting methods to interrupt the worker. The AVH alert was hypothesized to be the best possible case for alerting the participants. The tasks used with the AVH alert were the same set used throughout the study. No modifications were performed through this part of the study. Eleven participants were recruited for this part of the study.

5.2.1.1 Response Time and Second Task Completion Time

Two different time measurements were recorded for each task: response time and completion time. Table 5.1 summarizes the reaction and task completion times collected for the AVH alert. Response time refers to the time when the alert started to when the participant started raising his or her hands. Completion time refers to the elapsed time between when the alert started to when the participant finished raising his or her hands. Both times were taken to grasp how quickly the participants would react and could change to a different task after being alerted.

Table 5.1. Response and secondary task completion times using AHV alerting method.

TASK TYPE	AVERAGE RESPONSE TIME (SECONDS)	AVERAGE COMPLETION TIME (SECONDS)
BUILD	0.49±0.15	1.28±0.47
ORGANIZE	0.54±0.21	1.37±0.57
DISASSEMBLE	0.57±0.25	1.33±0.47
TRANSPORT	0.51±0.22	1.44±0.60
MAINTAIN	0.49±0.20	1.43±0.68
CONVERSE	0.49±0.14	1.03±0.35

The participants tended to behave in two ways when alerted. They were either surprised into reacting fast, which was coupled with them jumping as they raised their arms, or they viewed that completing the initial task was more important than acknowledging the alert and completing the secondary task. The participants responded to the alert at approximately the same time, regardless of the type of activity they were working on as the primary task.

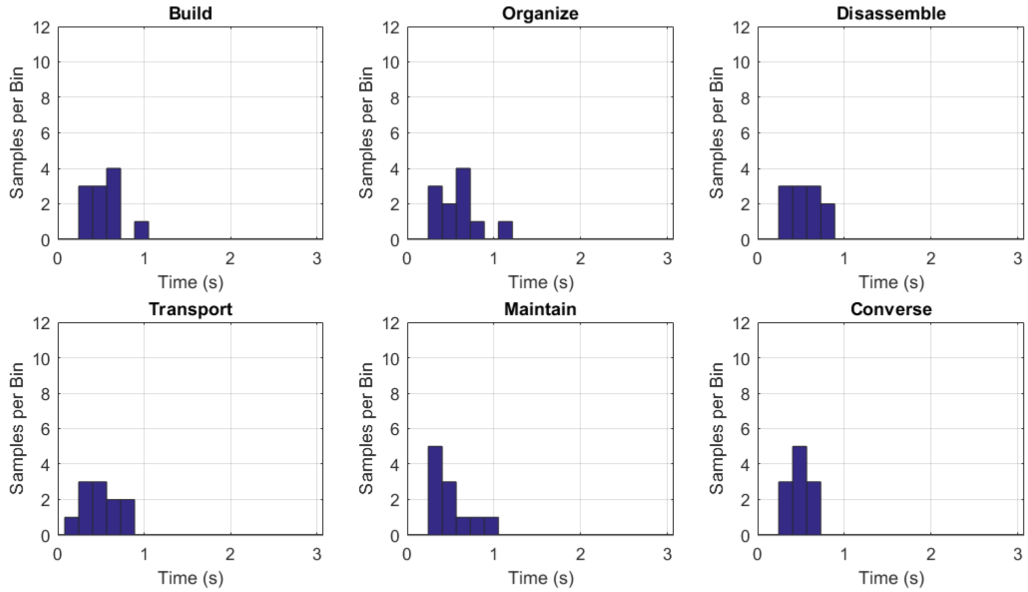

Figure 5.2. Reaction times across all activities for AHV alerting method.

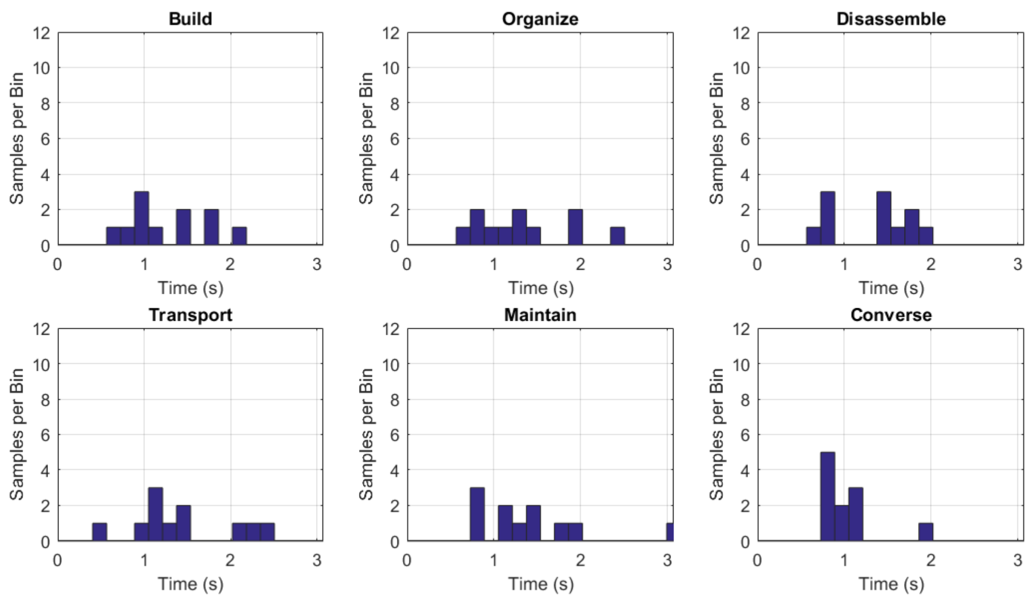

Figure 5.3. Secondary task completion times for the AHV alerting method.

Figure 5.2 and 5.3 were histograms of reaction and secondary task completion times for each of the six primary tasks. The best second task completion time was 0.63 seconds for the Build task. This participant was shocked by the alert and completed the second task quickly. The energy used derived from the alarm seemed to have been funneled into responding to the alert. The worse response time was 3.07 seconds for the Maintain task. The participant was concentrating on repairing the pyramid during a particularly noisy part of the auditory noise. The participant did not recognize the alert and did not perceive it as important as finishing the tower.

5.2.1.2 Qualitative Analysis

The following paragraphs and figures describe the qualitative data derived from the study. Most of the data was from the survey responses, participant comments during the study, and significant interactions that the participant had during the study. The survey was performed throughout the study. After the participant had reacted appropriately to the alert, he or she was asked to discern which alert alerted him or her first and last. More about the survey can be found in Chapter 4, Proposed Studies. The participants' comments were collected through the survey. The important interactions between the user and the vest were noted, and these interactions normally consisted of how the participants interacted with the alerting vest and the tasks.

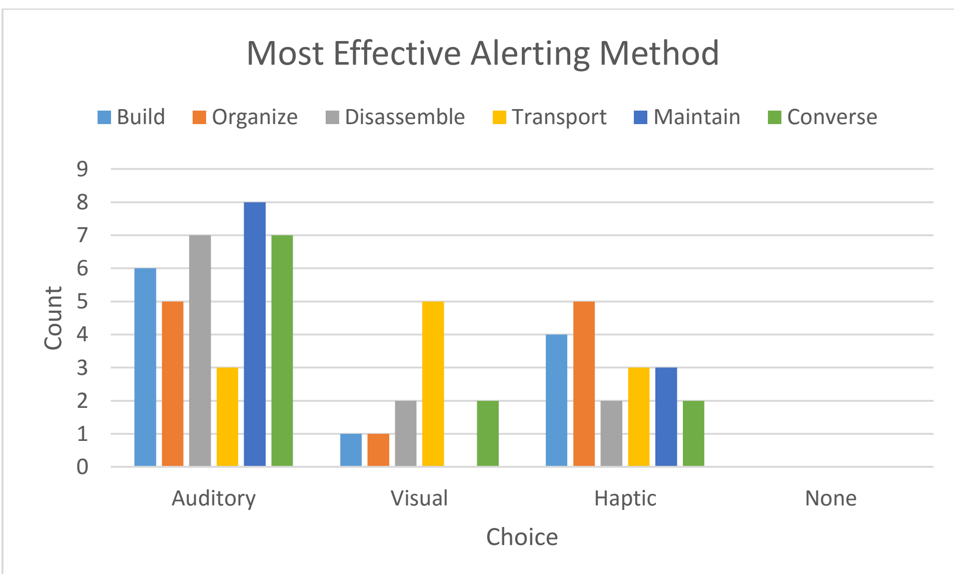

Figure 5.4. Survey results of what best alerted the participants for the AHV alerting method. The horizontal axis shows how many participants viewed an alert part. The vertical axis shows the different alert options.

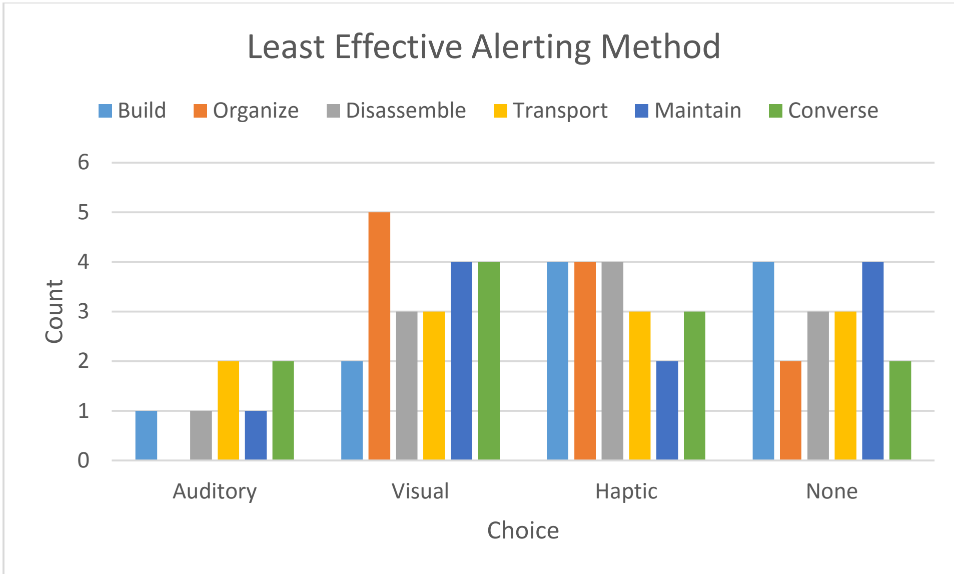

Figure 5.5. Survey results of what was not as effective for alerting participants for the AHV alerting method. The horizontal axis shows how many participants viewed an alert part as ineffective. The vertical axis shows the different alert options.

As shown in Figure 5.4, the auditory alerting method was perceived to be the most effective overall of the alerting methods, followed by the haptic alerting method. The only task where another alert did better was for the Transport task. Visual was considered the least effective, but multiple participants remarked that they noticed the visual alert first. The visual was not recognized as an alert until another alert, usually the auditory alert, was noticed. The lack of recognition caused the visual part of the alert to be seen as ineffective compared to the other alerts, which was why the visual part of the alert was perceived worse as shown in Figure 5.5. Approximately thirty-six percent of participants thought that all of the alerts worked equally well for them. As a note, the "None" choice was offered for participants who thought all of the alerts were equally effective.

The AHV alert was given to eleven people. At the end of the study session, the participants were given a survey consisting of five alert-based questions [12] [37]. Each of the questions was structured using a Likert scale, where people had to answer whether they strongly agree, agree, are neutral, disagree, or strongly disagree with a statement. There were plenty of opportunities for participants to justify their choices in the survey.

Sixty-four percent of participants strongly agreed and the rest of the participants agreed the vest effectively supported the rapid reaction to important information. Forty-five percent of participants strongly agreed and the rest agreed that the appropriate reactions to the alert were intuitive and obvious. Eighty-two percent of participants strongly agreed and nine percent agreed the AHV alert was distinguishable from the background noise. The one participant who remained neutral had difficulty hearing the alert. He found the alert to be difficult to recognize throughout the activities. Sixty-four percent of participants strongly agreed and twenty-seven percent agreed they trusted the vest would alert them properly. One participant responded neutrally to this statement, because she was unable to hear the auditory part of the alert during the entire session. Seventy-three percent of participants strongly agreed and eighteen percent agreed the alert, and thus the secondary task, was more important than the primary task. One person disagreed that the alert was more important than the primary task.

Some participants noted that they did not perceive the light-based and auditory noise to be distracting enough during the study. As a note, multiple flashing light sources were present throughout the room, and the auditory noise was set to be approximately 20 dB higher than the auditory alert. Some participants perceived the vest as bulky. Other participants liked having the multiple alerts but wished that parts of the alert took more precedence during different tasks. For example, some participants wanted the haptic and visual alert to be stronger than the auditory alert when they were performing the Converse task. These participants thought that changing the environment would change their thoughts about the construction vest.

5.2.1.3 Insights

From these results, one can see that the auditory alert was perceived to be the most noticeable alert. The participants recognized the auditory alert as important. The haptic and visual alerts were not as quickly understood when compared with the auditory alert. However, for the Transport task, the visual alert was considered to be much more appropriate compared to the other two alerting methods. The fact that the visual alert excelled in one category compared to the other alerts may mean that auditory alerts do not work for all different environments. Also, a few participants noted that they found parts of the alert similar to the environmental noise. Thus, they ignored parts of the alert combination. Each of the three alerting parts could be ignored depending on the scenario. For example, if the audio part of the alert sounded similar to the audio noise, then that participant would pay attention to the haptic and visual parts instead.

While the visual alert was not perceived to be an effective alert across all tasks, participants commented that they noticed the visual alert first. These comments show that the visual alert was worth exploring more. Therefore, two more cases were explored: HV and AV. The HV alert explores how the participant performs without an additional auditory alert. Also, we will examine which of the two alerting methods are noticed first by participants. The second case scrutinizes how well auditory and visual alerting systems would work together. This reasoning was based on how the visual alerting method tended to work when the auditory one did not work as well.

5.2.2 Visual-Haptic Alert Combination

For the HV alert test case, the visual and haptic alerts were used together for alerting. Twenty subjects participated in the study using the HV alert. The main six tasks remained the same. The secondary task remained the same as well. Once the second task was completed, the user was asked state which alerting method alerted the most and least effectively. The testing procedure remained unchanged.

5.2.2.1 Response Time and Second Task Completion Times

Response and completion time were collected for the HV alert. The quantitative results were shown in Table 5.2 on the next page. The users tended to respond slower to the set of alerts for each of the tasks. This trend was noticed across all tasks. On average, the participants would start responding approximately 0.3 seconds later compared to the first case's results, which can be found in Table 5.1.

Table 5.2. Response and secondary task completion times using the HV alerting method.

TASK TYPE	AVERAGE RESPONSE TIME (SECONDS)	AVERAGE COMPLETION TIME (SECONDS)
BUILD	0.72±0.20	1.16±0.27
ORGANIZE	0.84±0.34	1.37±0.47
DISASSEMBLE	0.72±0.25	1.20±0.36
TRANSPORT	0.81±0.30	1.42±0.38
MAINTAIN	0.74±0.37	1.23±0.40
CONVERSE	0.81±0.31	1.26±0.37

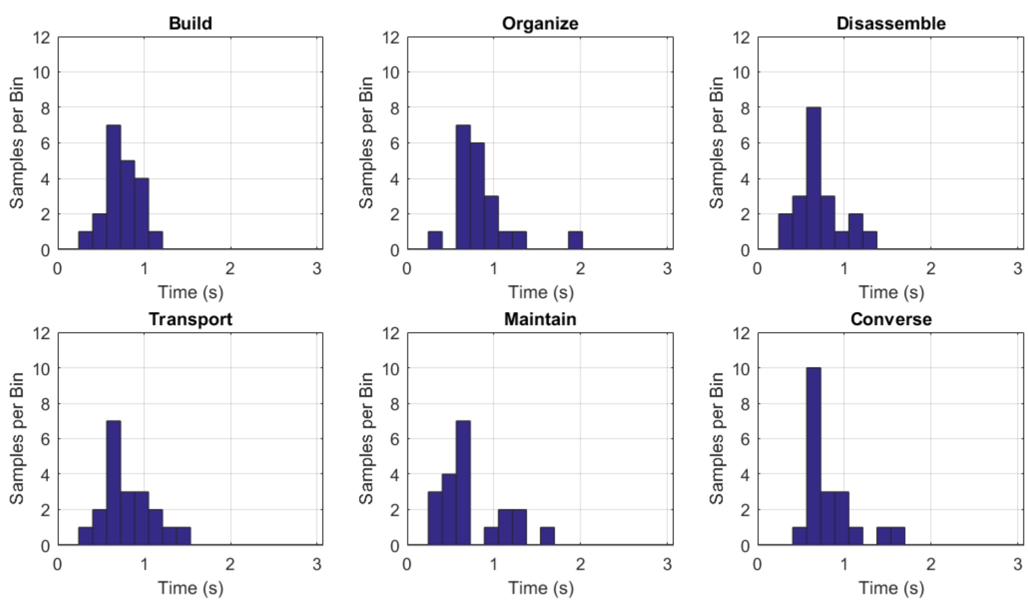

Figure 5.6. Reaction times across all activities for HV alerting method.

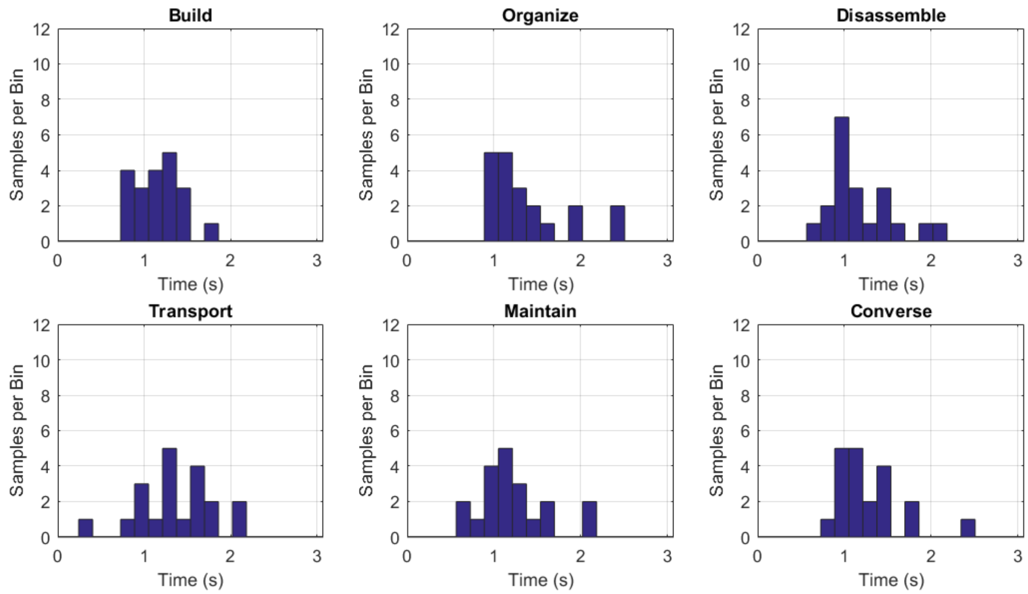

Figure 5.7. Secondary task completion times across all activities for HV alerting method.

As shown in Figures 5.6 and 5.7, the HV results had fewer statistical outliers regarding task completion. This change in results was because participants needed more training time to become familiar with the alert. The training phase cannot be completed until the participant could recognize the alert in a low noise environment. The average response times told a different story. The standard deviation of the mean response times was much larger compared to the AHV case. Participants had some difficulty readily recognizing the alert during noisy situations. More will be discussed in the upcoming sections.

5.2.2.2 Qualitative Analysis

The following paragraphs and figures describe the qualitative data derived from the study. Most of the data was from the survey responses, participant comments during the study, and significant interactions that the participant had during the study. The survey was performed throughout the study. After the participant reacted appropriately to the alert, he or she was asked to discern which alert alerted him or her first and last. More information about the survey was detailed in Chapter 4, Proposed Studies. The participants' comments were collected through the survey. The important interactions between the user and the vest were noted, and these interactions normally consisted of how the participants interacted with the alerting vest and the tasks.

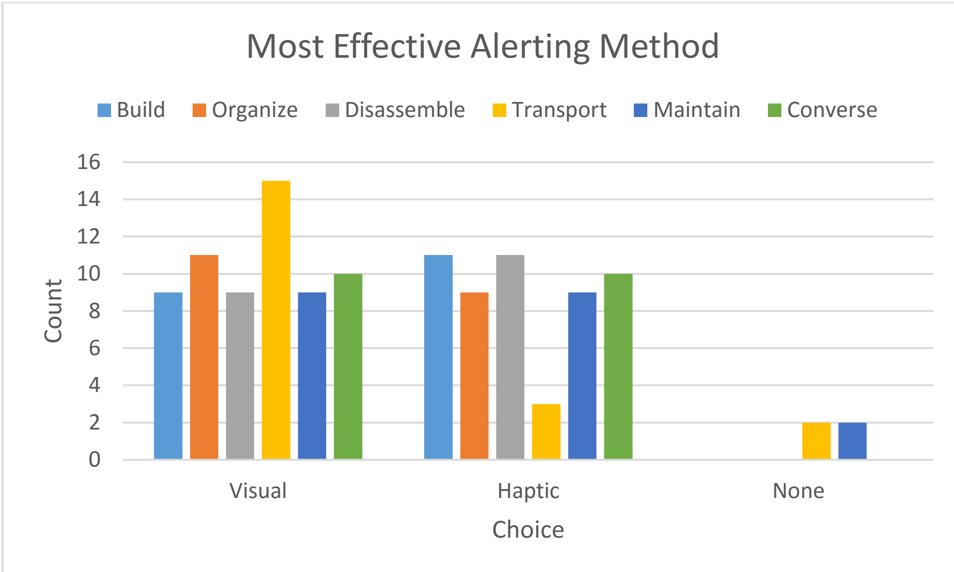

Figure 5.8. Survey results of what best alerted the participants for the HV alerting method. The horizontal axis shows how many participants viewed an alert part. The vertical axis shows the different alert options.

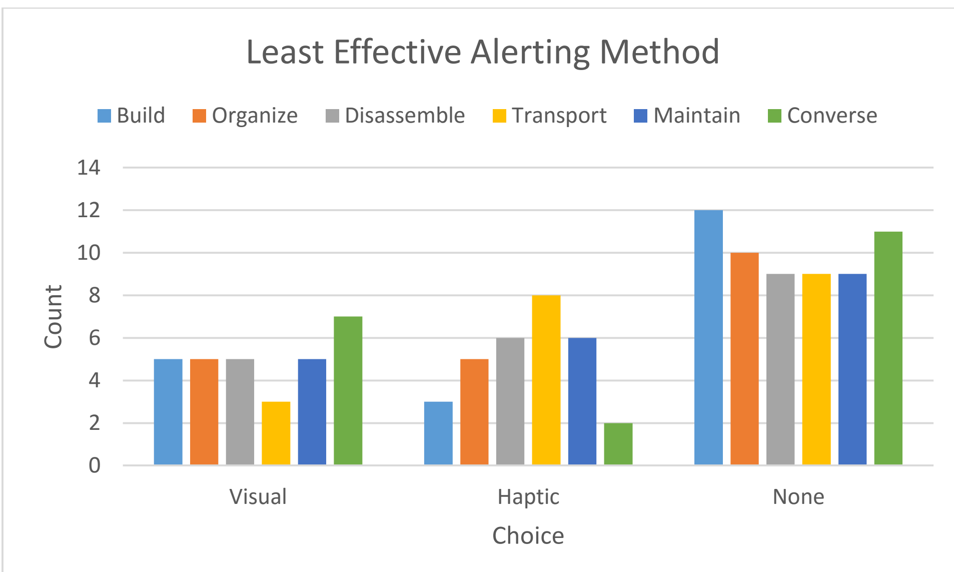

Figure 5.9. Survey results of what was not as effective for alerting participants for the HV alerting method. The horizontal axis shows how many participants viewed a part of the alert as ineffective. The vertical axis shows the different alert options.

Figures 5.8 and 5.9 show that people perceived visual and haptic alerts as similarly effective across most of the tasks. As a note, the "None" category was an option given to participants in case they thought neither answer was appropriate for the question. When asked which alerting method was the least effective, most participants who chose "None" thought that the alerts were similarly effective. The Transport task was the only task where participants greatly preferred one alerting method over the other. For that task, participants preferred the visual alerting method over the haptic.

The HV alert was assigned to twenty people. At the end of the study session, the participants were given a survey consisting of five alert-based questions [12] [37]. Each of the questions was structured using a Likert scale, where people had to answer whether they strongly agree, agree, are neutral, disagree, or strongly disagree with a statement. There were plenty of opportunities for participants to justify their choices in the survey.

Sixty percent of participants strongly agreed and the rest of the participants agreed the vest effectively supported the rapid reaction to important information. Thirty percent of participants strongly agreed, fifty-five percent agreed the appropriate reactions to the alert were intuitive and obvious. Fifteen present did not agree or disagree the reaction to the alert was intuitive and obvious. They found the main tasks very interesting and stated they wanted to complete the tasks before doing the secondary task.

Thirty-five percent of participants strongly agreed and fifty percent agreed the HV alert was distinguishable from the background noise. The rest of the participants remained neutral. The participants who remained neutral recognized different parts of the alerts during different tasks. The alert strength seemed to change for these people, which made it harder to notice the alert over the noise. Fifty-five percent of participants strongly agreed and forty percent agreed they trusted the vest would alert them properly. One participant responded neutrally to this statement, because she thought the alert had an auditory element to it. Forty-five percent of participants strongly agreed and forty percent agreed the alert, and thus the secondary task, was more important than the primary task. Two people remained neutral for this statement, and one person disagreed that the alert was more important than the primary task. The one person who disagreed thought that the visual alert did not break his concentration, which then did not distract him from the primary task.

5.2.2.3 Insights

The interesting result from the second case was that the participants viewed the haptic and visual alerts are similarly effective. For most tasks, either alerting method worked similarly for the participants. However, the visual alert worked exceeding well for the Transport task. The area around the haptic alert was scrunched and wrinkled during the Transport task, most likely making the haptic alert less effective compared to the visual alert.

A recurring theme throughout the HV alert part of the feasibility study was the participants noticing the visual part of the alert before the haptic part. Both alerting methods were initiated at the same time at the highest intensity. Another recurring theme was each alerting piece was more effective than the other while performing different parts for each of the activities. The participants deemed the haptic alert less noticeable and the visual alert more visible while bending over. On the other hand, many participants considered the visual alert less effective when they were concentrating on a task in front of them, such as talking to another person.

Some participants had differing opinions. One participant stated that the visual alert did not break his concentration, but the haptic alert did. Another participant noted that the visual alert was easily visible. Many participants had a combination of those two opinions, which may mean both alerts were viewed similarly in the test. Due to how well the visual alert did compare to the haptic alert for the Transport task, the visual alert was paired with the auditory alert for the third possible alerting method.

5.2.3 Auditory-Visual Alert Combination

The third case presented in this thesis examines how well auditory and visual alerting systems would work together. This reasoning was based on how the visual alerting method tended to work when the auditory one did not work as well. The main six tasks remained the same. After being alerted, the participants were expected to stop the first task and to raise their arms, which was considered the second task. Once the second task was completed, the user was asked to state which alerting method alerted the most and least effectively.

5.2.3.1 Response and Secondary Task Completion Times

Response and secondary task completion times were collected for the AV alert. Response time refers to the time when the alert started to when the participant started raising his or her hands. Completion time refers to the elapsed time between when the alert started to when the participant finished raising his or her hands. Both times were taken to grasp how quickly the participants would react and could change to a different task after being alerted. The quantitative results are shown in Table 5.3. Overall, the users being tested with the AV alerting method responded faster compared the HV alert and similarly to the AHV alert.

Table 5.3. Response and secondary task completion times using the AV alerting method.

TASK TYPE	AVERAGE RESPONSE TIME (SECONDS)	AVERAGE COMPLETION TIME (SECONDS)
BUILD	0.62±0.45	1.20±0.56
ORGANIZE	0.68±0.24	1.22±0.36
DISASSEMBLE	0.46±0.13	0.93±0.21
TRANSPORT	0.58±0.17	1.24±0.29
MAINTAIN	0.50±0.30	1.02±0.41
CONVERSE	0.48±0.11	0.9±0.19

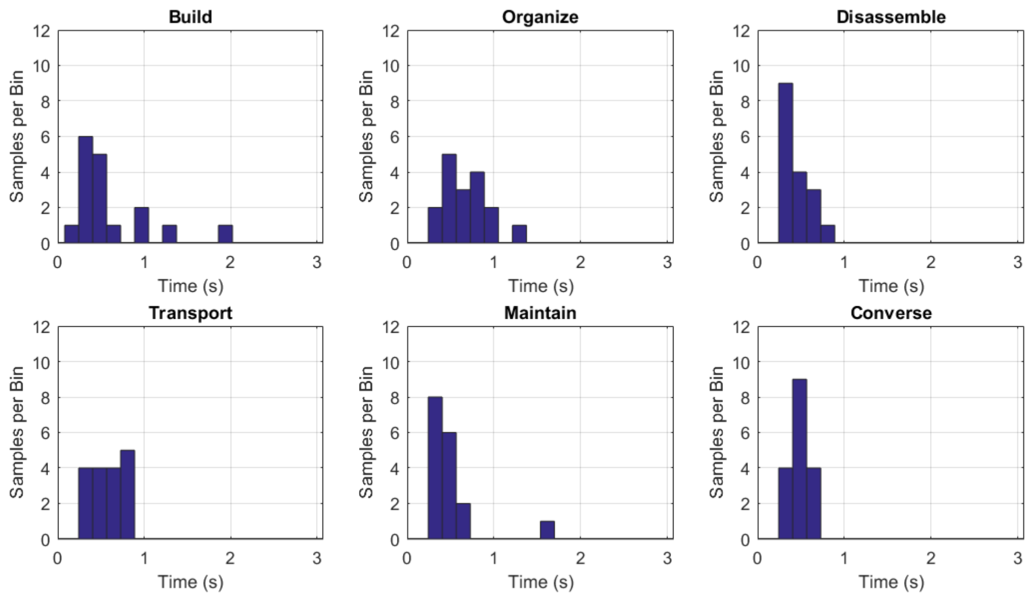

Figure 5.10. Reaction times across all activities for the AV alerting method.

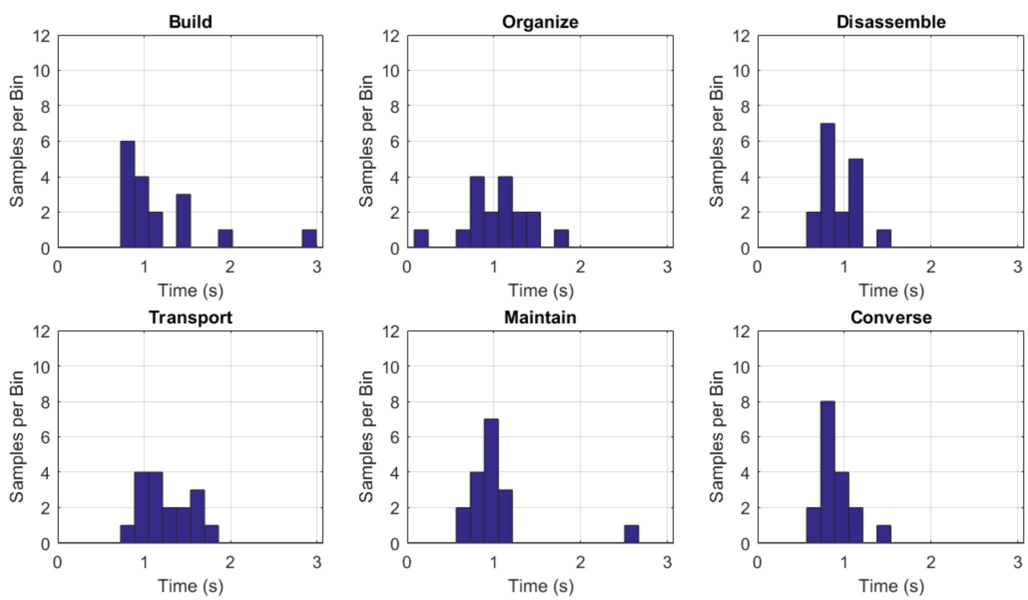

Figure 5.11. Secondary task completion times across all activities for the AV alerting method.

As shown in Figures 5.10 and 5.11, the AV results had more statistical outliers in terms of reaction time and secondary task completion time than the HV alerting method, but a similar amount compared to the AHV method. The secondary task completion times, based on the figures, seem to be more likely to resolve to one point if there was more data. The outliers from the Build and Maintain tasks were participants who tended to notice and pay attention to only the auditory noise.

5.2.3.2 Qualitative Analysis

The following paragraphs and figures describe the qualitative data derived from the study. Most of the data was from the survey responses, participant comments during the study, and significant interactions that the participant had during the study. The survey was performed throughout the study. After the participant had reacted appropriately to the alert, he or she was asked to discern which alert alerted him or her first and last. More information about the survey was detailed in Chapter 4, Proposed Studies. The participants' comments were collected through the survey. The important interactions between the user and the vest were noted, and these interactions normally consisted of how the participants interacted with the alerting vest and the tasks.

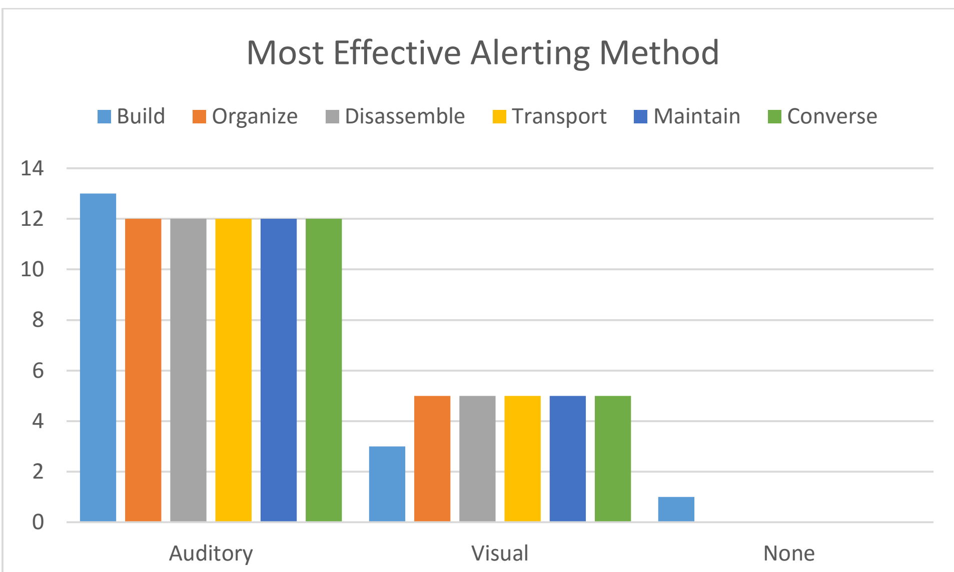

Figure 5.12. Survey results of what best alerted the participants for the AV alerting method. The horizontal axis shows how many participants viewed an alert part. The vertical axis shows the different alert options.

Figures 5.12 and 5.13 show that people perceived the auditory alert more effective that the visual alert for all of the tasks. As a note, the "None" category was an option given to participants in case they thought neither answer was appropriate for the question. When asked which alerting method was the least effective, most participants who chose "None" thought that the alerts were similarly effective. At least one of the alerting methods was chosen as effective per task. However, about half of the participants thought neither alerting method was ineffective. In this case, the auditory part was viewed favorably while the visual part was viewed neutrally at best.

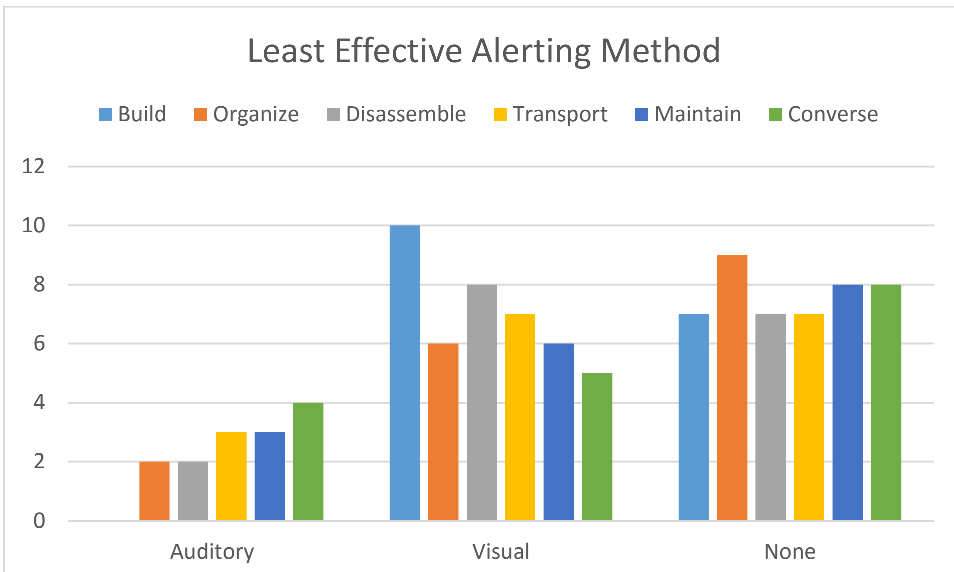

Figure 5.13. Perceptions of what was not as effective for alerting participants for the AV alerting method. The horizontal axis shows how many participants viewed a part of the alert as ineffective. The vertical axis shows the different alert options.

The AV alert was assigned to seventeen people. At the end of the study session, the participants were given a survey consisting of five alert-based questions [12] [37]. Each of the questions was structured using a Likert scale, where people had to answer whether they strongly agree, agree, are neutral, disagree, or strongly disagree with a statement. There were plenty of opportunities for participants to justify their choices in the survey.

Fifty-three percent of participants strongly agreed and the rest of the participants agreed the vest effectively supported the rapid reaction to important information. Forty-one percent of participants strongly agreed, and forty-seven percent agreed the appropriate reactions to the alert were intuitive and obvious. The rest did not agree or disagree the reaction to the alert was intuitive and obvious. The neutral participants stated that the auditory alert could be detrimental to people's hearing. They were concerned with the welfare of possible future user's hearing health because the auditory signal was another piece of noise in an already noisy environment.

Fifty-three percent of participants strongly agreed and thirty-five percent agreed the AV alert was distinguishable from the background noise. One participant remained neutral, and another disagreed. One participant responded neutrally to this statement because she thought that the power of the auditory signal changed over the duration of the activity. She stated that the visual alert was equally noticeable throughout the session. Another participant, one who strongly agreed with the statement, found the auditory alert easy to hear over the noise. The participant who disagreed did not leave a comment.

Fifty-three percent of participants strongly agreed and forty-one percent agreed they trusted the vest would alert them properly. One participant responded neutrally to this statement because she thought that the power of the auditory signal changed over the duration of the activity. Seventy-one percent of participants strongly agreed and six percent agreed the alert, and thus the secondary task, was more important than the primary task. Eighteen percent remained neutral, and one participant disagreed with the statement. The participants who remained neutral or disagreed with statement admitted they enjoyed performing the task, so they either paid attention to one part of the alert or no part of the alert. If they were going to pay attention to one part of the alert, they listened for the auditory alert.

5.2.3.3 Insights

The interesting result from the AV case was that the participants viewed the auditory alert as superior for all tasks. However, many participants stated that neither alert piece was inferior to the other. Some participants voiced concern of the auditory alert being detrimental to the person wearing the vest. As a note, the auditory signal remained the same strength as it was in the AHV case.

The recurring theme of the visual signal being noticed first but not recognized did not happen in this part of the study. Participants either stated that they primarily paid attention to the auditory alert, or they found the visual alert to be similarly effective no matter which task they were performing. If they were going to focus on an alert part, they would focus on the auditory piece. These comments line up with the result in Figure 5.13, where about half of the participants viewed neither alerting method to be necessarily worse than the other. They were paying attention to the auditory alert over the visual alert in most cases. A few participants commented that they liked the visual alert for when they were unable to hear the auditory alert due to attention or noise reasons.

5.3 Discussion of Results

In the upcoming subsections, we will discuss the results presented in Section 5.2. The first part will compare the alerting methods, tasks, and response/secondary task completion times to each other using ANOVA. From there, the trends will be summarized. The second part of this discussion will be delving deeper into the qualitative data, specifically the critical incidents observed throughout the study. At the end of the discussion, a suggestion for an optimum alerting method will be presented.

5.3.1 Comparison of Results Across Methods and Implications

For the feasibility study, alerting modality, activity type, and response time were analyzed using a two-way ANOVA to determine how much of an effect a part had on the others. The alerting modality can be either the AHV, HV, or AV alerting methods. The tasks were the six tasks used in the feasibility study. For this part, the response time was used for the time element of ANOVA, where response time was the time between when the alert started and when the participant started reacting to the alert.

A significant effect of modality was found on time ($F(2,180) = 15.07$; $p < 0.05$) while no significant effect was found for task on time ($F(5,180) = 1.46$; $p > 0.05$). No significant two-way interaction was observed between task and modality on the response time ($F(10,180) = 0.75$; $p > 0.05$). Since a significant effect was discovered for modality on time, a Tukey test was applied to the data. Based on the results, we discovered the significant difference resided between the AHV and HV alerting methods and the HV and AV alerting methods.

Table 5.4. Average reaction times across all alerting methods.

TASK TYPE	**AVERAGE RESPONSE TIME (SECONDS)**		
	AHV	HV	AV
BUILD	0.49±0.15	0.72±0.20	0.62±0.45
ORGANIZE	0.54±0.21	0.84±0.34	0.68±0.24
DISASSEMBLE	0.57±0.25	0.72±0.25	0.46±0.13
TRANSPORT	0.51±0.22	0.81±0.30	0.58±0.17
MAINTAIN	0.49±0.20	0.74±0.37	0.50±0.30
CONVERSE	0.49±0.14	0.81±0.31	0.48±0.11

These results point to finding we observed in the average response times across each of the alerting methods. Table 5.4 shows the response times for each alerting method and each task and is presented for the convenience of the reader. We theorize that this was because of the auditory part of the alert. People preferred to pay attention to, and thus recognize, the auditory alert compared to the other alerts. Therefore, both the AHV and AV alerting methods are very similar to each other in terms of response time. Figure 5.15, shown on the next page, presents the response times for each alerting method visually. Since there was no significant interaction between response time and the primary tasks, the response time data can be combined.

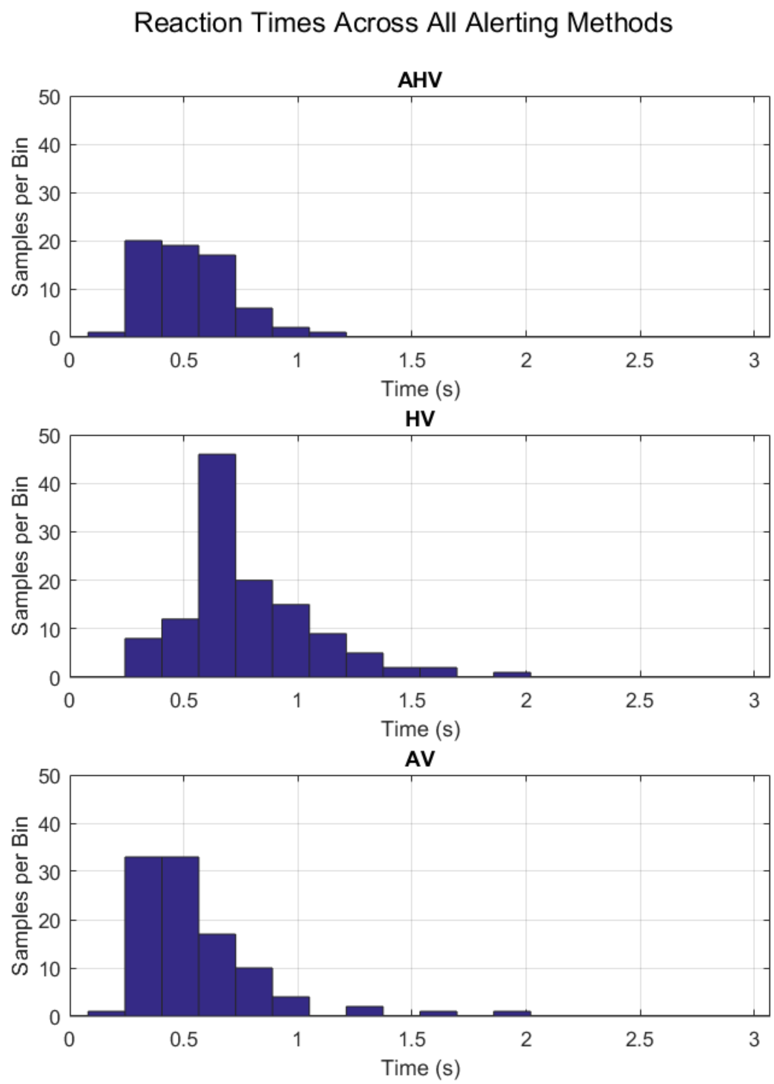

Figure 5.14. Reaction times for all activities per alerting method.

To see how fast people responded after recognizing that they were alerts, secondary task completion time was examined. The two-way ANOVA was repeated with this change. A significant effect of modality was found on time ($F(2,180) = 3.99$; $p < 0.05$) while no significant effect was found for task on time ($F(5,180) = 1.53$; $p > 0.05$). No significant two-way interaction was observed between task and modality on the response time ($F(10,180) = 0.53$; $p > 0.05$). The significance between alerting modality and secondary task completion time was much weaker compared to the significance found between alerting modality and response time. This difference was probably because the secondary task completion times for the AHV alerting modality, as shown in Figure 5.15, were thinly spread across two seconds rather than being concentrated at one point.

Since a significant effect was discovered for modality on time, a Tukey test was applied to the data. Based on the results, we discovered a significant difference in the mean response times per alerting modality between the AHV and AV alerting methods. This result was different from the Tukey results that used response time for the comparison. As shown in Table 5.5, the task completion times were consistently smaller for the AV case over the AVH case.

Table 5.5. Average secondary task completion times across all alerting methods.

TASK TYPE	AVERAGE COMPLETION TIME (SECONDS)		
	AHV	HV	AV
BUILD	1.28±0.47	1.16±0.27	1.20±0.56
ORGANIZE	1.37±0.57	1.37±0.47	1.22±0.36
DISASSEMBLE	1.33±0.47	1.20±0.36	0.93±0.21
TRANSPORT	1.44±0.60	1.42±0.38	1.24±0.29
MAINTAIN	1.43±0.68	1.23±0.40	1.02±0.41
CONVERSE	1.03±0.35	1.26±0.37	0.9±0.19

While the participants reacted to the alert about the same amount of time, the participants who were given the AV alert method stopped their task and completed raising their hands faster compared to the other alerting methods. The distribution of secondary task completion times for the AV method was clustered closer its mean compared to the results from the AHV method. The increased task completion speed could mean that the participants perceived the alert and more urgent, which means they needed to raise their hands as fast as possible. However, little of the user data supported this conclusion.

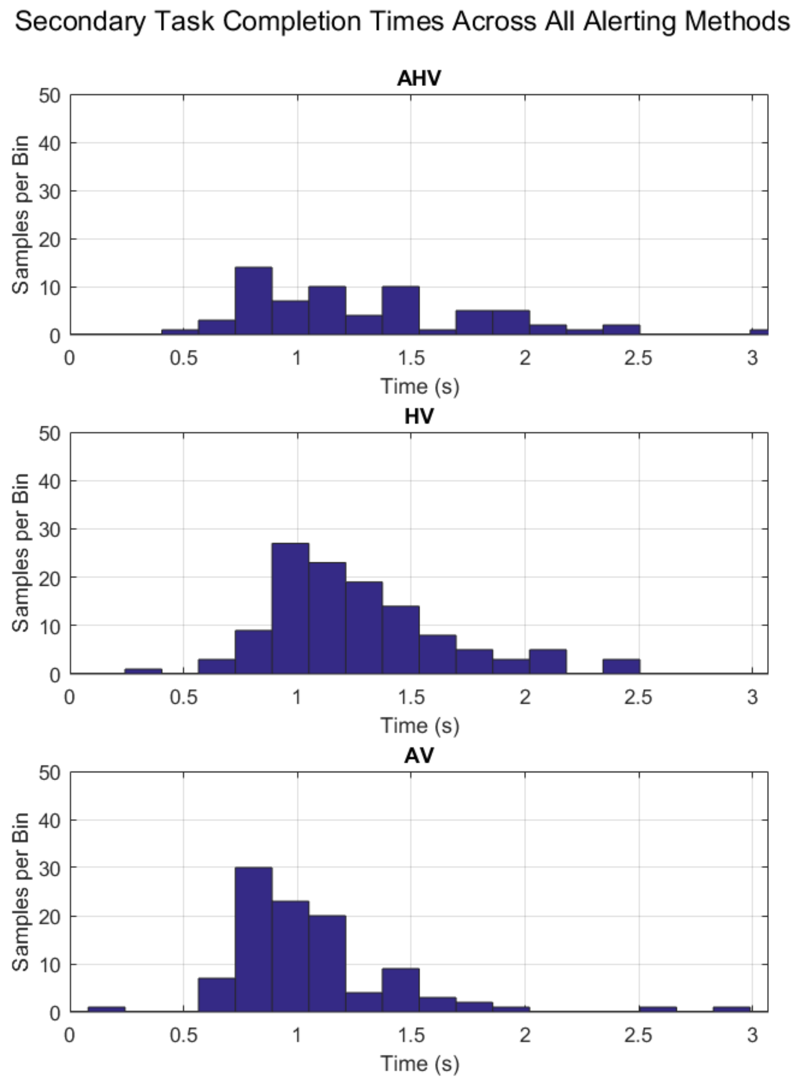

Figure 5.15. Secondary task completion times across each alerting method.

5.3.2 Important Incidents Observed Through the Study

Two important critical incidents occurred in this study: people surprised by the alert to respond fast and people ignoring the visual part of the alert for another part. Multiple people were shocked by the AHV alert into reacting quickly. The alert surprised them, causing them to jump visibly while they were performing the assigned primary task. They would place what they were doing down, onto the table, in a fluid motion. These people admitted to being engrossed in the task.

However, as noted by responses from participants in the HV and AV test sets, being engrossed did not correlate with people being surprised when the alert was triggered; some people slowly noticed the alert while others noticed it suddenly. None of the study participants were surprised to the point that they dropped or destroyed what they were doing. Also, none of the participants faced a decrease in task performance. Their reaction times and secondary task completion times remain similar across each activity. Part of that may be because of the training session. The conclusion we can come to from these interactions was that those who were shocked by the alert tended to perceive it faster throughout the session, even if they stopped jumping while alerted.

The second, and more interesting, incident was that participants noticed the visual part of the alert faster compared to the other components. Each of the three alerting combinations had a light element. According to comments and reactions obtained through the AHV and HV alert sets, the visual alert was normally perceived first, but there was a delay between the notice and the reaction to the alert. In an HV session, one participant stated that he did not like the visual alert because it was not distracting enough. He paused when he noticed the visual part of the alert. However, the haptic part broke his attention, which was when he acknowledged the alert. Throughout the rest of the session, he continued to ignore the visual alert.

Similar reactions happened among other participants, where they would notice the visual part before the others and either (a) not connect it to the rest of the alert, or (b) choose to wait for another part of the alert before reacting. A question that surfaced here was whether the visual alert also encouraged participants to respond to the alert, similar to how the auditory and haptic alerts do or was the visual part viewed as unimportant when participants noticed it. Future work would be needed to ascertain why people perceived the alert parts the way they did. The phenomenon observed with the visual alerts warrants more attention in case it could be used as a pre-alert for the wearer. However, this thesis will not seek such an answer as the question was outside of its purview.

5.3.3 Feasibility Study Conclusion

Auditory is considered the most effective alerting element based on both reaction time and secondary task completion time. Both alerting methods that involved auditory had faster reaction times compared to the one without auditory. This result lines up with the results from the preliminary study. Also, people preferred the auditory element of the alert.

Some people thought that each of the alerts worked well in different cases. For example, light worked best in situations where the person was bending over, and auditory worked best when the person was not talking. Haptic performed similarly to auditory except when the participants were performing the Transport task. The haptic alert's effectiveness changed when the participants were carrying or holding big objects, such as a box. Overall, participants enjoyed having a multimodal alert. Therefore, the best alert would include the auditory part along with either the visual or haptic pieces.

During each of the tasks and across all of the alerting methods, comprehension and understanding were considered not as important compared to how fast the person reacted. We assumed that if this was a real situation where a person would be in danger, the person would evade first rather than think about why they need to evade. Since we know that people will react consistently and quickly using the AHV and AV alerting combinations, future work can explore alerting methods for different situations. One set of situations would involve making the alerting methods adaptable to different noise environments. Another situation would involve issuing different levels of alerts given the danger level.

We did not formally study how the interruptions affected the primary tasks in this study. This is partially because the participants did not continue the same task after they were alerted. We wanted to capture how the thought of each of the alerts during the study, which meant they needed to stop the task and report on their impressions of the alerting combination. Restarting the task after such a break would give us weaker information about how the interruptions affected the quality of the primary task.

What we were able to gather was how participants' performance changed over the session. For the feasibility study, little to no change occurred in terms of response time and secondary task completion time. The participants' times were similar across each of the activities. Also, participants performed the tasks similarly during the session. Each participant would complete each of the tasks with few to no errors. A survey such as the Self Evaluation of Anxiety (STAI) questionnaire could be used to determine what the participants' anxiety levels were after each of the alerts [39]. However, the main goal of the feasibility study was to figure out which alerting method worked well at getting people to react quickly.

Chapter 6

Conclusion and Future Work

The work presented in this thesis is meant for those who wish to design vest-based alerting systems. The design rationale was straightforward: keep the auditory-based alerts near the person's ears, cover the vest shoulders with LEDs to improve visibility, and to place the haptic motors on relatively stable and sensitive places such as close to the collar of the vest. Through the studies presented in this work, we showed that the alert placements were sound and effective. Also, none of the alerting methods were ill-suited for the vest, especially after the changes implemented to the visual alert.

The uncontested result is that the auditory alert proved to be the most popular, followed by both haptic and visual. All of the alerting methods that employed auditory elements correlate with faster reaction times. Out of the three alerting combinations tested, the audio-visual alert worked the best in terms of reaction time and user perception. The audio-haptic-visual alert is close in terms of reaction time and secondary task completion time and could even be considered similar to the audio-visual alert. Their performance was due to the visual and auditory elements of the alerting combination. The haptic-visual alert was favored by participants because they believed it would cause less damage to the worker if he or she was working in a high noise area. That alert would be better suited for warnings, which is when the worker is not quite in danger, or in situations where the worker was surrounded by slow-moving vehicles, even if this alert would still work if the system gave the worker 6 – 7 seconds to react [4].

6.1 Insights Found During the Studies

Through these studies, we learned about the limitations and strengths of visual alerts. If the person cannot see the alert, then the alert is ineffective; however, the visual alert is normally the first to be noticed, even if it is not the first to be recognized as an alert. This result is because of people's preference of auditory alerts. They would pay primarily pay attention to the auditory alert, sometimes to the exclusion of the other alerting methods.

Some participants voiced concern about the effect of auditory alerts in already noisy environments: construction workers have issues with workplace hearing damage. The auditory alert, even if it was set to a lower intensity compared to the noise around it, could still increase the damage done to workers. The analysis of the effects of auditory alerts on humans in already noisy environments was outside the purview of this thesis, but the concern should be recognized and examined in future systems. The auditory alert should not harm the worker over time.

In response to this sentiment, other participants voiced interest in replacing the auditory alert with the haptic alert, but participants responded approximately 0.3 seconds slower to the alerting combination without the auditory alert. This may mean that the haptic alert could be examined for less pressing situations, such as situations when construction workers are in danger of being struck by heavy machinery and other slow-moving vehicles.

6.2 Future Work for Vest-based Alerting Systems

The first way this work can be expanded is by implementing programs such as collision avoidance algorithms or workplace-wide alarms onto the vest. The alerting program used within the tests triggers the alert randomly throughout the study session. Based on Forsyth et al.'s work, a collision avoidance program would need access to GPS coordinates (on both the worker and on-coming traffic) and a DSRC radio to instantiate a communication channel between the vest and the on-coming traffic [4]. During this time, roadside construction workers should be involved in the integration. They will need to wear the system each day, so their insights on how they would want to interact with the system will be important for future progress.

The second path involved more qualitative work in the form of interviews, interruption and anxiety surveys, and participatory design. This work would be needed to understand why people perceived each of the alerting methods the way they did, especially the visual alert. We found in this research that the visual alert was consistently noticed first. Developing a person's visual alert comprehension could be used to further improve reaction speeds to alarms and alerts.

Another possible future path this research can take is observing how groups of people interact with each other and the system when alerts take place. Important questions to answer in this part would focus on how to people react when the person was not reacting fast enough and would the group and notice that a person is in danger before the accident occurs. No research about group dynamics was gathered during the studies. However, alerts, such as the visual alert, may work better in group settings rather than personal. The visual alert may be imperative for warning the car and heavy machinery drivers. Those and similar questions would be needed to grasp a better understanding of how this alerting system would affect perceived safety within a worksite.

A possible fourth path would be to make the alerting methods adaptive. They would be able to adapt to different noise environments and different contexts. The drive behind this future path was foreshadowed in the results: some alerting patterns were more appropriate for different contexts. If a person is carrying materials around all day or using a jackhammer, then a haptic alert would not be as effective as the audio or visual alerts. Also, a loud audio alert is inappropriate in quieter environments. Therefore, a possible future direction would be to see which alerting method is appropriate for different situations and devise a way to change between the different methods.

Finally, this work can be expanded into different realms, serving as a platform to protect people such as police officers who work on busy roadways and highway workers. An alerting vest is useful for many of those who work or walk by the road. The big question would be how should the alerting vest be changed for each different situation. Should there just be an aesthetic change? Would there be inappropriate alerts? How do we want people to react when alerted? Questions such as these would need to be answered when the vest is applied to different cases.

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Appendix

Survey for Feasibility Study

Biometric Information

Complete after signing the consent form. Required questions have red stars next to them. If you have any concerns, please tell the researcher performing the study.

* Required

1. Age (in years) *

   ....

2. Gender *

   Mark only one oval.

   - Male
   - Female
   - Other No comment

3. Height *

   Write as 'FT, IN.' Example response: '5,11'

   ....

4. Weight (to the nearest 'lb') *

   ....

5. Do you have any known visual/hearing impairment? * Mark only one oval.

- Yes (If yes, please talk to the researcher)
- No

6. Do you have an attention deficit disorder that you are aware of? * Mark only one oval.

- Yes (If yes, please talk to the researcher)
- No

Build Activity Questions

Complete after the task.

7. Which alerting method worked the best? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

8. Which alerting method worked the worst? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

9. Why? (optional)

Organize Activity Questions

Complete after the task.

10.
Which alerting method worked the best? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

11.
Which alerting method worked the worst? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

12.
Why? (optional)

Destroy Activity Questions

Complete after the task.

13.
Which alerting method worked the best? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

14.
Which alerting worked the worst? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

15\.

Why? (optional)

Transport Activity Questions

Complete after the task.

16\.

Which alerting method worked the best? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

17\.

Which alerting method was the worst? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

18\.

Why? (optional)

Maintain Activity Questions

Complete after the task.

19.

Which alerting method worked the best? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

20.

Which alerting method worked the worst? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

21.

Why? (optional)

Converse Activity Questions

Complete after the task.

22.

Which alerting method worked the best? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

23.

Which alerting method worked the worst? * Mark only one oval.

- Auditory
- Haptic
- Visual
- None

24.

Why? (optional)

Impressions

Complete at the end of the session.

25.

The vest effectively supports rapid reaction to important information. * Mark only one oval.

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

26.

Appropriate reactions are intuitive and obvious. * Mark only one oval.

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

27.

If you had any issues, what did you have issues with?

28.

The alerts are easy to distinguish from the background. * Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

29.

If not, why?

30.

The designed vest instilled confidence that the alert would be noticed. * Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

31.

It was obvious when a reaction to the alert was more important than the current task. * Mark only one oval.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

32.

Any final comments?