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Exploring Feedback Mode Redundancy in Handheld Scanning Tasks

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Exploring feedback mode redundancy in handheld scanning tasks

By

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Exploring feedback mode redundancy in handheld scanning tasks

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This study was conducted to determine whether or not combining feedback modes resulted in improved operator performance, given a specific task and environment. A common industrial handheld scanner with multiple feedback settings was used to assess four experimental feedback conditions (auditory, auditory-visual, auditory-tactile, and auditory-visual-tactile) during simulated box scanning tasks. Participants completed four-50 box trials in a single test session where boxes were scanned and located based on the feedback provided regarding the scan. Task completion time and ranks, hit rate and false alarms were recorded. While the auditory-visual-tactile feedback combination produced the fastest performance time, there was no statistically significant improvement in operator performance between the four feedback settings tested. By understanding the most important feedback modes, or combination of such, identification of the best scanner settings for this device and task can be made.

Keywords: Feedback modalities, redundant feedback, handheld scanner

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CHAPTER I

INTRODUCTION

Feedback is a common part of everyday life. Whether a person notices it or not, they are provided with feedback while using any kind of system throughout their day (e.g., tones to indicate buttons have been depressed, increases/decreases in vehicle speed, vibrations to indicate a call is incoming). Some systems incorporate a single type of feedback, such as a beep or a vibration, while others incorporate multiple, and redundant, feedback types, such as a beep and vibration simultaneously. Simple or redundant feedback effectiveness depends on the situation and how that feedback is to be used. For example, redundant feedback is more effective under high workload in challenging environments (e.g. tasks that involve problem solving), whereas simple feedback is better in low stress environments (e.g. simple manual tasks) [5].

One situation where feedback modes can be critical is in large distribution facilities. This is due to work volume, fast work pace, and need to minimize errors, among others. Scanning activities in delivery service companies serve many purposes (e.g., to collect inventory on the location of items within the facility or sort packages for processing and routing). Handheld scanning devices are used to scan barcodes and provide feedback to the operator to determine whether a scan was successful or if there is an error and to provide information to the operator on next work steps. Positive feedback (indicating a correct scan) allows the operator to continue with the tasks at hand.

Negative feedback (indicating an incorrect scan) requires the operator to follow a different procedure, such as routing an item to an inspection area or performing a re-scan.

Scanners may be equipped with multiple feedback modes (e.g. visual, auditory, and tactual) to improve operator performance and minimize scanning errors. These modes can be used redundantly or individually. It is unknown which combination, if any, of the three modes enhance operator performance or which modes operators rely on to complete tasks in a distribution facility environment in particular. By understanding the most effective feedback modes, identification of preferred scanner settings for this device and task can be made, ultimately leading to improved operator efficiency and productivity.

1.1 Research Objective

The objective of this experiment was to determine whether or not the feedback modes or combination of such resulted in improved operator performance, given a specific task and environment. Most scanning tasks use auditory (e.g. grocery stores, credit card scanners, key locks), so it is reasonable to assume auditory feedback is the primary feedback mode for these types of tasks. Visual and tactile feedback were added to the primary mode to investigate the effect of feedback redundancy on task completion time, errors, hit rate, and false alarm rate. The independent variables for this experiment were feedback, gender, and prior job experience in scanning tasks.

1.2 Hypothesis

The following hypotheses were investigated:

1. The addition of a second or third feedback mode will result in improved operator performance compared to that of only auditory feedback, as measured by hit rate, task completion time and false alarm rates.
2. Of the three redundant mode combinations, the auditory-visual combination will result in the highest operator performance, as measured by task completion time, hit rate, and false alarm rate.
3. Of the three redundant mode combinations, the auditory-visual combination will be regarded as the most useful, as measured by survey data.

CHAPTER II

LITERATURE REVIEW

2.1 Feedback Modes

The most prominent types of feedback used are auditory, visual and tactile [11]. Auditory feedback is transmitted using sounds or tones of varying frequency, duration, etc.; visual feedback is transmitted through flashes of light, words, etc; and tactile is usually transmitted through vibrations. Of these, visual feedback is the most common feedback modality [1]. However, auditory feedback has been found to be more effective overall in increasing productivity, quality, and worker satisfaction than visual feedback [4]. Auditory feedback has also been used to focus users' attention and keep task vigilance in place [11]. Research shows that auditory feedback from human-computer interfaces can improve performance and increase usability [2]. Auditory feedback allows the brain to process information in the temporal domain while visual feedback is better for processing information in the spatial domain [2]. Since auditory feedback is primarily a temporal sense, humans are more sensitive to changes in acoustic signals over time [2]. Tactile feedback use is commonly used to break operators' attentional fixation, particularly when the same event is occurring over and over or the operator is searching for a signal [5]. Reaction times are improved using tactile feedback over using auditory or visual feedback [9].

2.2 Multiple Modes at Once

Combinations of feedback have been shown to be more effective in some cases versus single feedback modes [5]. Suggestions have been made that tactile feedback can often be masked by an operator's normal movements in situations and auditory feedback may be masked by background auditory noise [10]. For this reason, multimodal feedback may provide operators with confirmatory information without mental overload [10]. Human cognitive and physical abilities relating to attention, working memory, and decision making can be maximized through using multimodal feedback [10]. It is best to use multimodal feedback in high workload environments when communication of risk is of high importance [5]. Multimodal feedback reduces the likelihood that a signal will be missed [5]. Bimodal feedback enhances user effectiveness and efficiency while lowering mental demand [11].

Different feedback mode combinations are useful in different types of situations. Combing auditory and visual feedback is most effective under normal working conditions in single-task scenarios in which operator(s) have one task to focus on (e.g. metal detector operators in airports.) [5]. Combing visual and tactile feedback are more effective in multiple task situations with high workload (e.g. distribution package handler) [5]. Combing tactile and auditory feedback has resulted in better operator performance in perceptually high-demanding tasks (e.g. quality inspectors) than auditory feedback alone [8,10]. Research has shown that the addition of feedback modes to visual feedback enhances the performance of computer technology operators, including scanning devices [14].

2.3 Scanning

Scanning input is a temporal task, meaning operators press a button when a cursor is over the required target [2]. Research has shown that for temporal tasks auditory feedback is often better than visual feedback [2]. In a distribution environment, bar code scanning can identify and track incoming items [13]. Bar codes on items allow operators to track the status and movement of items within the system, and in select environments where to place scanned items for further processing [13]. Evidence has shown that the implementation of scanners decreases misidentified products [3]. Further, operators that develop a rhythm to scanning often complete tasks or select items for scanning more rapidly [2]. When the operator recognizes that the barcode has not scanned, the operator is recognizing a signal. In this case, the signal means something is wrong. It is imperative that if a signal occurs the operator recognizes it and takes the correct measures to fix the problem.

2.4 Signal Detection Theory

SDT states that a signal can be modeled as present or absent [12]. In work environments, operators must differentiate signals from noise, both internally and externally. External noise is anything in the environment other than the signal itself. Internal noise refers to the noise in neural responses [7]. There are four possible outcomes associated with signal detection theory: Hit, Miss, False Alarm, and Correct Rejection. Figure 2.1 demonstrates these outcomes.

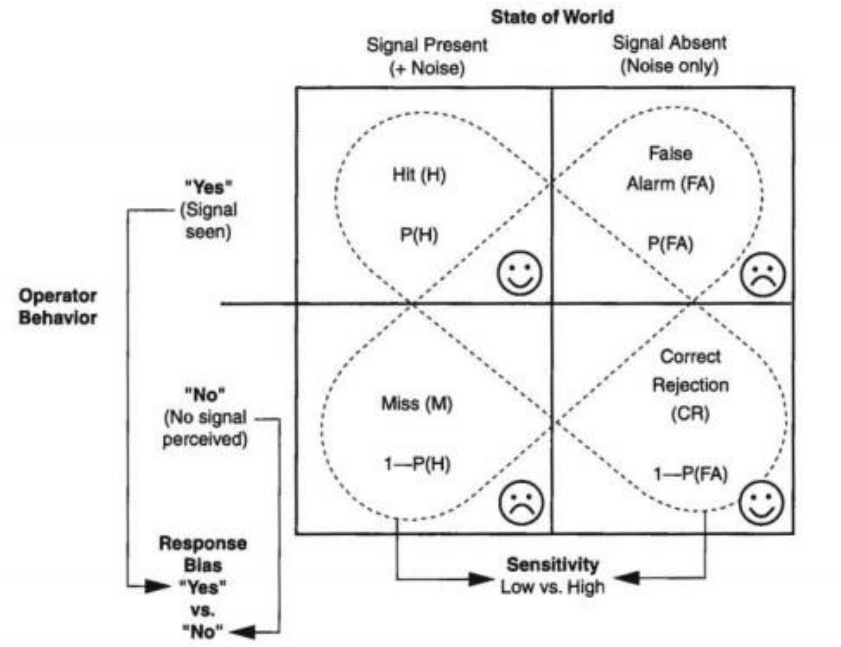

Figure 2.1 Outcomes of Signal Detection Theory [12].

When an operator has a “hit” this means the operator has correctly detected the signal. In a distribution center, a hit would be the operator putting the correct package into the correct container to be sent where it needs to go. A “correct rejection” means that the operator says there is no signal, and there actually was no signal. An example in a distribution center would be when an operator scans a package, receives feedback that it is in the wrong place, and puts it aside to be sent to the right place. These two outcomes are the desired outcomes. If an operator has a “miss” this means that the operator said there was no signal when there actually was. For example, placing scanned box in the wrong container. A “false alarm” means that the operator said there was a signal when there was not one. For example, an operator attempts a scan, there is no positive

feedback that the scan occurred in placing in a container for further processing. These two outcomes are not desirable as they represent errors.

To determine how discriminable a signal is from no signal, the separation and spread of the noise-alone and signal-plus-noise curves are used. The separation is divided by the spread to determine an estimate of the strength of the signal; which is a measure of internal response [7]. The ease of discriminability while utilizing feedback modes on a handheld device allows for better operator performance in scanning tasks. If the curves are too close, the operator cannot distinguish between device feedback and environmental noise. By separating the curves, operators can discriminate between the two. For example, an operator would be able to tell that an audio beeping sound was from the handheld device, rather than from a nearby forklift.

In the current study, each feedback setting was tested to find out whether or not multiple redundant modes were better than auditory mode alone, and if so, which combination of modes was better for operator performance. This was done by collecting errors and calculating hit rate and false alarm rates as well as recording completion time of the task for each feedback setting.

CHAPTER III

METHODS

3.1 Materials

The experiment took place in the Human Factors and Ergonomics laboratory located in McCain 300. The device used for this experiment is the Intermec SF61B wand scanner (Figure 3.1). This device is a common scanner used in delivery service companies and was used to represent handheld scanners of this type. This scanner allows for visual (LED light), auditory (tone), and tactile (vibration) feedback. Multiple settings for each of these can be selected. For this study, the settings for each feedback mode were as follows: Vibrate duration—200 ms, LED light duration—1000 ms, sound duration—80 ms.

Figure 3.1 Intermec SF61B Scanning Device [6].

Cardboard boxes with bar-coded labels were used to model a package-scanning task. Barcode 128 (correct scan) was on 40 of the boxes and barcode 39 (incorrect scan) was on 10 of the boxes (Figures B.1 & B.2 in Appendix B). The barcodes had subtle differences and the participants were not able to tell the difference between the two.

3.2 Participants

A total of 36 participants were included in the study. This target number was determined using a power of 0.80 and α=0.05. Effect size was estimated to be 0.02 with a standard deviation of 0.03. Participants were recruited from the student population at Mississippi State University through word of mouth. Once recruited, participants were sent a survey on SurveyMonkey.com regarding availability. This survey also included questions about eyesight, hearing and nerve damage to serve as exclusion criteria for the study. Test sessions lasted one hour and participants were compensated at a rate of $10/hour.

Of the 36 participants, there were 19 male and 17 female with the average age being 22.11 (SD = 2.33 years) and 21.6 (n=8) percent having previous experience with a scanning job. All participants had good hearing and no nerve damage to the hands. Forty-five point nine percent (n=17) had perfect 20/20 vision while the other 54.1 percent (n=19) percent had 20/20 corrected vision with either contacts or glasses.

3.3 Procedure

Participants signed up to participate in the study through SurveyMonkey.com. Once a date and time for testing was confirmed, participants came to the Human Systems Engineering Laboratory to complete the study protocols. Upon arrival, participants were

asked to sign an IRB consent form. If the participant consented to the experiment, (s)he continued on with the study. If participants marked that (s)he had to use contacts or glasses to have 20/20 corrected vision, the researcher checked that participants were wearing such eyewear. Participants first completed a demographics questionnaire (Appendix A.1) and were given a job scenario as to explain what (s)he would be doing during the experiment (Appendix A.3). The table was labeled to reflect the job scenario (Figures B.3 & B.4). Participants were verbally informed of the difference between a correct scan and incorrect scan and were allowed to do practice scans on a sheet of paper filled with 10 barcodes (Barcode 128). Participants were told to press the button only one time on the handheld device to scan each box. If the handheld device emitted feedback for a correct scan, the participant was told to put the box on top of the table. If the handheld device emitted feedback for an incorrect scan, the participant was told to put the box underneath the table.

Participants scanned 50 boxes of size 8in x 8in x 8in using the Intermec SF61B scanning device with the device being set on a certain feedback mode or mode combination. During the task, the researcher used the timer on an iPhone 5 to time the participants to the nearest second. The time started when the participant scanned the first box and ended when the participant placed the last box on the table. After completing the task, the participant completed a brain teaser while the researcher restacked the boxes. The boxes were sorted in a way that no incorrect scan would be right after the other (Figures B.5, B.6, B.7 & B.8 in Appendix B). The shaded areas on the diagram represent the boxes that had a barcode with an incorrect scan. Regardless of the order of the feedback mode for each participant, the boxes were stacked in the same order every time.

Once the researcher was finished stacking the boxes, the participant started the task again with the scanner being set to have different feedback. This continued until all four trials were tested. Participants completed the overall survey (Appendix A.2) at the end of the final trial. Once this survey was completed, the participant completed the study. The flow of the tasks is shown in Figure 3.2 below. The order in which the tasks were completed were determined using a Balanced Latin Square as shown in Table 3.1 below.

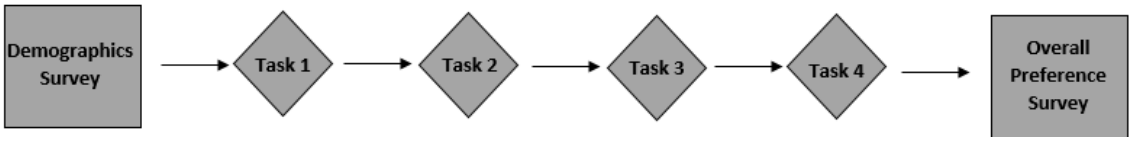

Figure 3.2 Task Flow

Table 3.1 Balanced Latin Square (n=4 conditions)

Participant									Task Order			
									1	2	3	4
1	5	9	13	17	21	25	29	33	Auditory	Auditory-visual	Auditory-tactile	Auditory-visual-tactile
2	6	10	14	18	22	26	30	34	Auditory-visual	Auditory-tactile	Auditory	Auditory-visual-tactile
3	7	11	15	19	23	27	31	35	Auditory-tactile	Auditory-visual-tactile	Auditory-visual	Auditory
4	8	12	16	20	24	28	32	36	Auditory-visual-tactile	Auditory	Auditory-tactile	Auditory-visual

During the experiment, a recording of the inside of a distribution center played through two speakers at 90 dB as to recreate the sound level in a distribution facility to add to the participants' stress level. Participants wore Laser Lite protective ear plugs to also recreate the feel of an industry setting.

3.4 Data Analysis

Data was entered into Microsoft Excel and then into IBM SPSS Statistics version 21 (SPSS IBM, New York, U.S.A).Appropriate descriptive statistics were calculated. The effect of the independent variables on task completion time were analyzed using repeated measures ANOVA, hit and false alarm rates were analyzed using the Kruskal-Wallis test, and Friedman's test was used for rank analysis. A Mann Whitney test analysis was used when analyzing demographics for hit rate and false alarm rate.

CHAPTER IV

RESULTS

A box plot was created for each dependent variable. Eight data points were determined to be outliers and were removed from the data set, resulting in 136 total data points for analysis. A value was considered an extreme outlier if it was at least three times greater than the IQR (Interquartile range) or at least three times less than the IQR. A log transformation was used on the time variable to satisfy the assumption of normality within ANOVA Non-parametric tests were used for the hit rate and false alarm rate variables, as no suitable transformation satisfied the normality assumption.

4.1 Task Completion Time

Table 4.1 below shows descriptive statistics for task completion time, based on the independent variables considered. The sample size listed is the number of data points analyzed (outliers removed), not number of participants, calculated as 36 participants times 4 trials minus 8 outliers, or 136 total data points.

Table 4.1 Descriptive Statistics: Task Completion Time (seconds)

	n	$\bar{x}$	***s***	**Min**	**Max**
Overall	136	267.0	73.5	124.0	473.0
Feedback					
Auditory	32	273.6	72.1	158.0	433.0
Auditory-Visual	32	265.7	77.7	162.0	472.0
Auditory-Tactile	36	267.7	73.5	124.0	473.0
Auditory-Visual-Tactile	36	261.4	73.5	168.0	460.0
Gender					
Male	72	258.8	73.7	124.0	472.0
Female	64	276.1	72.8	162.0	473.0
Prior Scanning					
Yes	29	295.5	68.0	173.0	392.0
No	107	259.2	73.3	124.0	473.0

It was expected that there would be a significant difference in combination modes over auditory alone. It was also expected that the auditory-visual combination would improve operator performance over the other two combinations of feedback. However, there was no significant effect of number of feedback mode on task completion time (F (3, 136) = 0.78, p = 0.509).

Demographics were investigated with regards to task completion time and a two-way ANOVA was run. There was a significant effect of prior scanning job (F (3,136) = 7.95, p = 0.006) and of gender (F (3,136) = 4.34, p = 0.039) on task completion time. The interaction of scanning job and gender was not significant (F (1, 136) = 1.47, p = 0.227). Participants with scanning job experience and females were slower than other participants (Table 4.1).

It was of interest to analyze task completion time as a gross measurement (rank) rather than a precise measurement (time). Each participant's task completion times were sorted from lowest to highest and assigned a rank 1-4 respectively (Figure 4.1). For

example, if a participant's task completion time was shortest for the auditory feedback condition, it received a rank of 1. Results of the Friedman's test show a significant difference in task completion time ranks ($X^2(3, N=32) = 8.87, p = 0.031$). The auditory-visual-tactile feedback combination setting had more number one ranks than the other conditions.

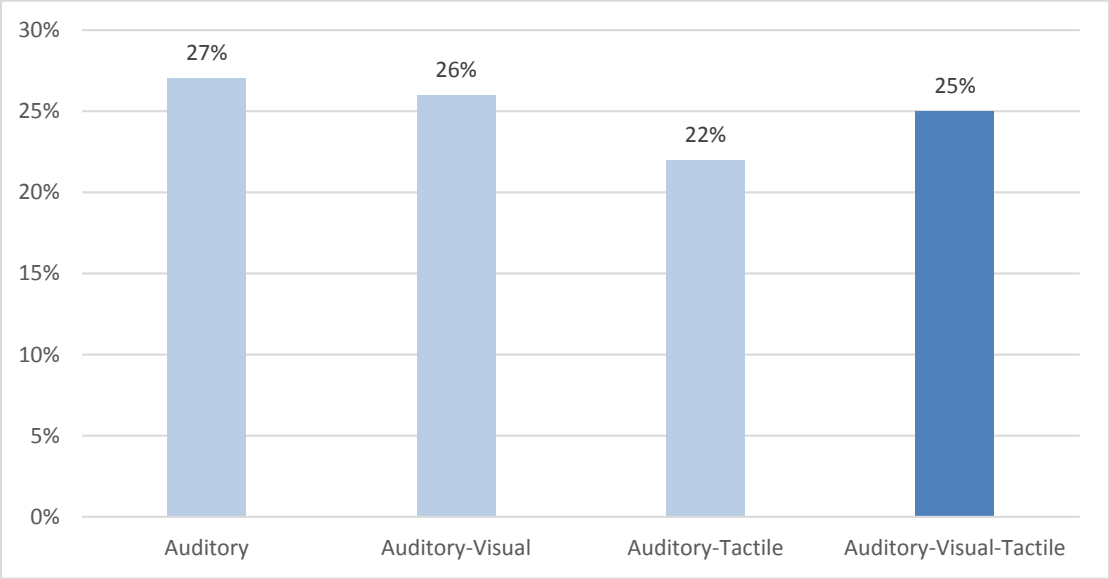

Figure 4.1 Distribution of Top Ranked Time Performance

4.2 Hit Rate

Table 4.2 below shows descriptive statistics for hit rate, based on the independent variables considered. As with task completion time, the sample size listed is the number of data points analyzed (outliers removed), not number of participants.

Table 4.2 Descriptive Statistics: Hit Rate (%).

	n	$\bar{x}$	***s***	**Min**	**Max**
Overall	136	96.3%	5.8%	73.0%	100.0%
Feedback					
Auditory	32	98.2%	2.7%	90.0%	100.0%
Auditory-Visual	32	98.2%	2.6%	93.0%	100.0%
Auditory-Tactile	36	94.9%	6.9%	73.0%	100.0%
Auditory-Visual-Tactile	36	94.4%	7.6%	78.0%	100.0%
Gender					
Male	72	96.2%	6.1%	73.0%	100.0%
Female	64	96.4%	5.6%	78.0%	100.0%
Prior Scanning					
Yes	29	96.5%	6.5%	73.0%	100.0%
No	107	96.3%	5.7%	78.0%	100.0%

It was expected that hit rates would be higher when using the combination settings. Specifically, when using the auditory-visual feedback combination hit rates were expected to be higher. There was no significant effect of feedback mode on hit rate (X^2(3, N=136) = 6.86, p = 0.077). There was also no significant effect on hit rate when analyzed by gender (U= 2294, p = 0.962) or by scanning experience (U= 1497, p = 0.754).

Hit rate rank order was also analyzed, and ranks were determined in the same manner as for task completion time (sorted lowest to highest then assigned a 1-4 number) (Figure 4.2). Auditory feedback alone had the highest number of number one rankings, though there was not a statistically significant difference between the feedback combinations (X^2(3, N=32) = 1.91, p = 0.591).

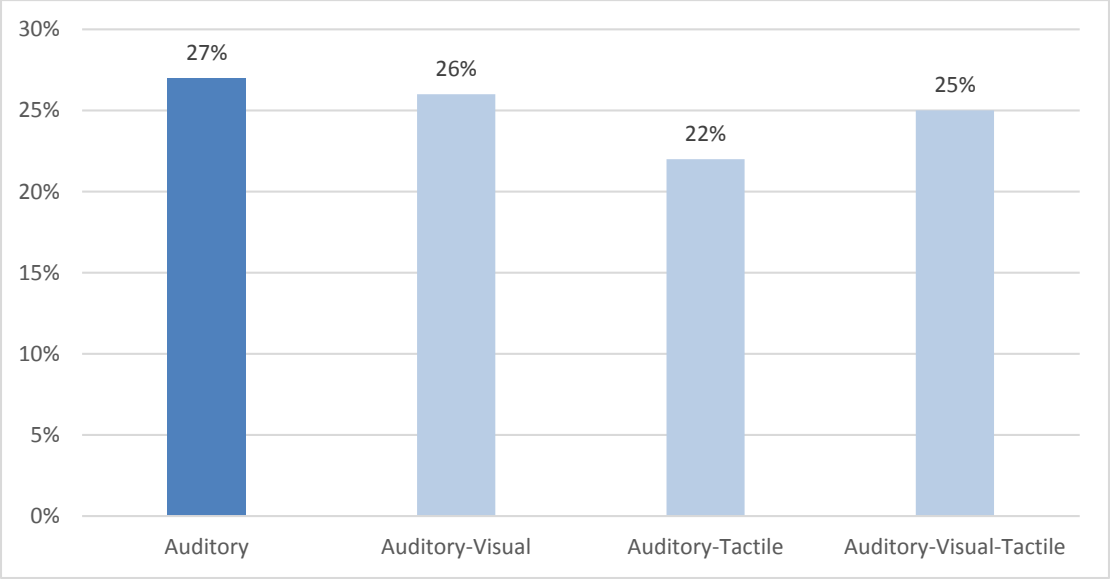

Figure 4.2 Distribution of Top Ranked Hit Rate

4.3 False Alarm Rate

Table 4.3 below shows descriptive statistics for false alarm rate, based on the independent variables considered. Again, the sample size listed is the number of data points analyzed (outliers removed), not number of participants.

Table 4.3 Descriptive Statistics: False Alarm Rate (%).

	n	$\bar{x}$	***s***	**Min**	**Max**
Overall	136	0.4%	1.9%	0.0%	10.0%
Feedback					
Auditory	32	0.6%	2.5%	0.0%	10.0%
Auditory-Visual	32	0.0%	0.0%	0.0%	0.0%
Auditory-Tactile	36	0.8%	2.8%	0.0%	10.0%
Auditory-Visual-Tactile	36	0.0%	0.0%	0.0%	0.0%
Gender					
Male	72	0.3%	1.7%	0.0%	10.0%
Female	64	0.5%	2.1%	0.0%	10.0%
Prior Scanning					
Yes	29	0.7%	2.6%	0.0%	10.0%
No	107	0.3%	1.7%	0.0%	10.0%

There was no statistically significant different found between the feedback conditions (X^2 (3, N = 136) = 5.36, p = 0.147). Further, no significant effect for gender, (U= 2260, p = 0.556) or scanning job experience, (U= 1488, p = 0.301) was found for false alarm rates. Ranking analysis of false alarm data was not conducted due to the low incidence of false alarms.

4.4 User Ratings

Participants reported the experiment to be an average stress level of 1.39 on a scale of 1 (not very stressful) to 5 (very stressful) with a standard deviation of 0.68. The scores ranged from 1 to 4, with only one participant rating the stress as a 4 and only one rating it as a 3. Participants rated whether or not (s)he could clearly see, hear and feel the feedback modes while using the Intermec SF61B scanning device, and perceived usefulness of each feedback mode (Table 4.4). All participants agreed to have clearly seen, heard and felt each feedback mode. All also agreed to finding all modes strongly useful with the exception of visual feedback.

Table 4.4 User Ratings for Clear and Useful Feedback Modes.

Rating Percentage (%)	Strongly Disagree				Strongly Agree
	1	**2**	**3**	**4**	**5**
Clearly hear beep	0.0	0.0	0.0	27.8	**72.2**
Clearly see green light	2.8	11.1	25.0	19.4	**41.7**
Clearly feel vibration	2.8	8.3	13.9	0.0	**75.0**
Auditory feedback useful	0.0	0.0	0.0	19.4	**80.6**
Tactile feedback useful	2.8	2.8	16.7	25.0	**52.8**
Visual feedback useful	11.1	11.1	**27.8**	22.2	**27.8**
Combination of more than one useful	0.0	0.0	8.3	5.6	**86.1**

Participants ranked the individual feedback modes according to which they most relied on while using the handheld scanning device, with the rank of 3 being the most relied upon (Figure 4.3). There was a significant difference in feedback mode ranks (F (3, 136) = 0.78, p = 0.509), with participants reporting that they relied the most on the auditory feedback mode followed by tactile and visual.

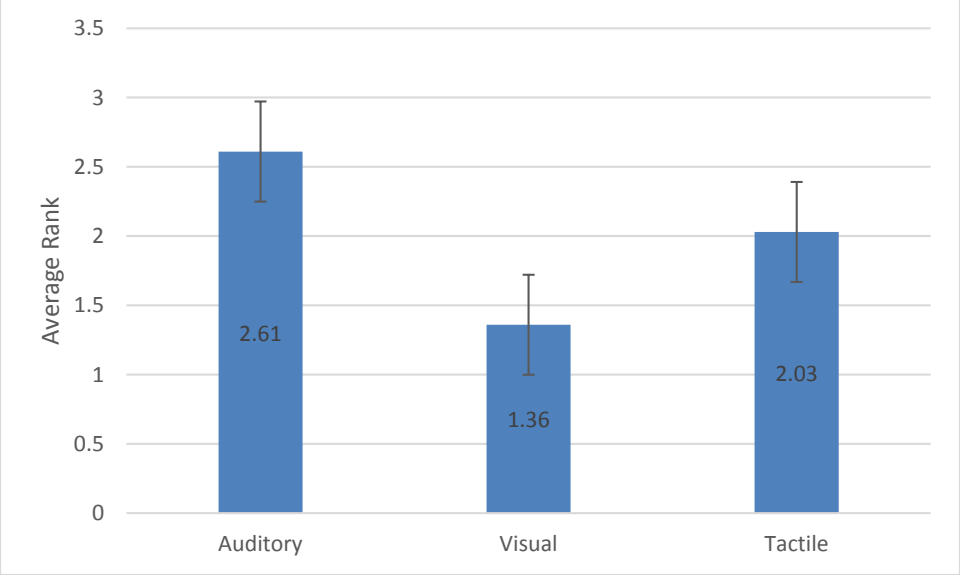

Figure 4.3 User Rank of Most Relied Feedback Mode.

Participants were asked to select which of the four feedback conditions they found most useful while using the scanner. It was expected that the auditory-visual feedback combination would be perceived as the most useful setting (Hypothesis 3). However, the auditory-tactile feedback combination was selected most often (Figure 4.4).

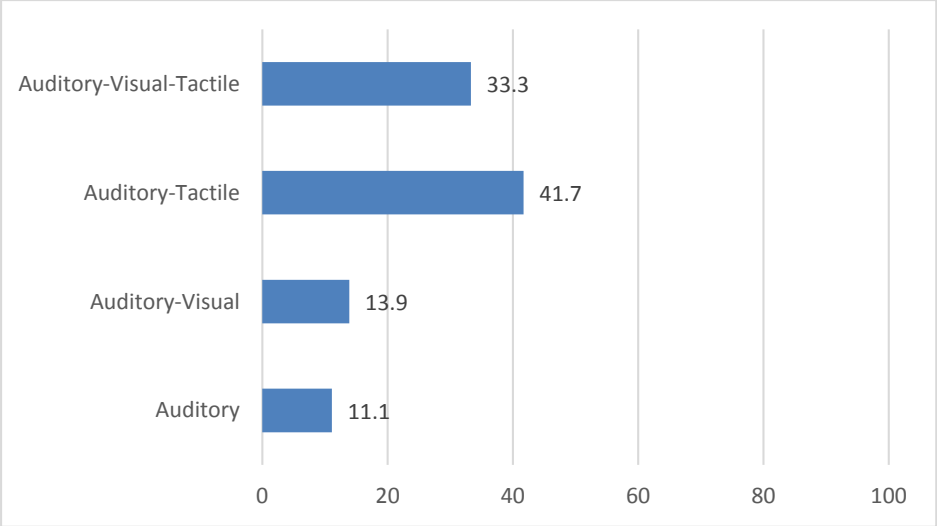

Figure 4.4 User Choice for Most Useful Feedback Setting.

Participants selected the notification most used for their personal phone settings in the demographics survey. There was a moderate positive correlation between the notification used for a text message and the perceived most useful setting (r (136) = 0.33, $p < 0.001$).

4.5 Personal Device Settings

The participants provided information on what notification was preferred for cell phone use and chose one notification for each type of cell phone task. When receiving a text message, e-mail, or calendar notification, most participants chose vibration as the setting they preferred most. When receiving a phone call, most participants chose a combination of notifications as their preference (Table 4.5). Table 4.6 shows the demographics for each notification preference. Those without previous scanning experience favored the combination setting for a phone call over those with previous scanning experience.

Table 4.5 Cell Phone Notification Preferences (%).

Notification Preferences (%)	*Vibration*	*Audio Tone*	*Visual setting*	*Combination*
Phone call	36.1	19.4	0.0	**44.4**
Text Message	**55.6**	16.7	0.0	27.8
E-mail	**38.9**	13.9	30.6	16.7
Calendar events/reminders	**33.3**	25.0	25.0	16.7

Table 4.6 Cell Phone Notification Preferences by Demographics (%).

Notification Preferences (%)	*Vibration*	*Audio Tone*	*Visual setting*	*Combination*
Gender (M/F)				
Phone call	61.5/38.5	28.5/71.5	0.0/0.0	56.3/43.7
Text Message	60.0/40.0	50.0/50.0	0.0/0.0	40.0/60.0
E-mail	64.3/35.7	20.0/80.0	54.5/45.5	50.0/50.0
Calendar events/reminders	50.0/50.0	55.5/44.5	33.3/66.7	83.3/16.7
Scanning Job (Y/N)				
Phone call	38.5/61.5	14.3/85.7	0.0/0.0	12.5/87.5
Text Message	25.0/75.0	16.7/83.3	0.0/0.0	20.0/80.0
E-mail	42.9/57.1	0/100.0	18.2/81.8	0.0/100.0
Calendar events/reminders	41.7/58.3	22.2/77.8	11.1/88.9	0.0/100.0

CHAPTER V

DISCUSSION

5.1 Discussion

The human brain is more sensitive to changes in sound [2]; which makes auditory feedback good for a task similar to this study because attention to signals is required. Tactile feedback is sometimes used to break attentional fixation on reoccurring events [5] which makes tactile feedback also good for this type of task due to the operator searching for a signal. Visual feedback is best for processing information [2], which could aid the operator in this type of task to make decisions on what is or is not a signal. Any of these modes could be argued to aid operator performance in some area. For this task, it seemed that no one type of feedback mode was better than the other.

There was no significant effect on user performance found between the four feedback combinations tested. Based on task time, hit rate, and false alarm rate, there was no mode that led to statistically significant improvements in user performance. Additionally, the redundant settings did not show a significant benefit over the single feedback mode setting. This finding is contrary to the benefits of redundant feedback reported in literature [8, 10]. This could mean that no one setting for this device is better than another for our chosen task, whereas the previously reported benefits could be domain specific. If that is the case, that could prove that feedback settings do not effect operator performance in industrial scanning tasks. If feedback settings do not effect

operator performance, then the devices could be customized to the way operators prefer to use them.

Female participants and participants with previous scanning experience had significantly slower task completion times. Participants with previous scanning experience could have been slower due to them being more careful when scanning compare to participants with no experience with a scanning job. The experienced participants would have been more careful because they had negative outcomes associated with poor scanning performance at work.

With feedback combination settings, participants were faster yet had lower hit rates. Participants were likely less attentive when multiple feedback modes were active due to their trust and reliance in their redundant system. One participant reported "*If I heard the beep I didn't have to look for the green light or pay attention to vibration.*" Another participant also said, "*In case I couldn't hear the beep, I relied on the vibration to confirm*" that the box has scanned correctly. While another participant reported that the combination settings made it "*easier to keep my workflow moving."* Paying less attention to the device because there are multiple modes to rely on can increase the productivity and workflow, but also decrease hit rate.

The single feedback setting had the slowest ranked performance, but the highest hit rates. This also supports the notion that the combination settings reduce vigilance. While using the single feedback, participants were forced pay more attention because they were only reassured that the box scanned with the first beep. This did slow down productivity, but the participants were more accurate in detecting signals.

Results show that the auditory feedback mode had the highest hit rates and was perceived as most useful by participants. Although the visual setting was not tested alone, these findings could support research that found auditory to be more effective overall in increasing productivity over visual feedback [4]. It also supports research demonstrating that auditory feedback focuses users' attention [11], improves operator vigilance [11], and improves operator performance on computer tasks [2]. . Humans are more sensitive to changes in acoustic signals [2] which could explain why the auditory setting led to higher hit rates.

Existing research also supports what the participants were saying about having a reassured feeling when using combination modes, as it has been proven that combination settings provide confirmatory information [10].The combination settings were perceived to be more useful than the auditory mode alone, according to the user survey. This could be because the combination settings helped the participants to work faster, which they likely perceived as most useful. It is human nature to quickly complete a task with the least stress possible. Having the combination settings helped the participants to decide quicker, pay less attention, and have less stress by being reassured from more than one feedback mode that the box had scanned.

For most companies, where quality is the most important aspect, it can be better to increase quality by increasing hit rate and taking the decrease in productivity. This would mean using a single feedback mode rather than a combination. Once this is done, productivity and speed can be evaluated later while still having high hit rates. If a company chooses to focus on productivity rather than quality of work, then they may decide that a combination feedback is best for them.

5.2 Limitations

There were many limitations to this study. The participant sample was limited to college students, which are not entirely representative of the worker population for scanning jobs. The majority of participants were also inexperienced with scanning tasks. The workforce may use different scanning techniques or methods that would be different from the participants used in this study. Although the environment was created in an attempt to replicate a work environment, not everything was the same as it would be in an actual distribution center. The floors did not shake or vibrate and there were no other workers around. The participants in this study also only scanned a total of 200 boxes. Realistically, operators in distribution centers scan thousands of boxes a day, truly effecting their fatigue and vigilance.

Due to effect size for task completion time and false alarm rate being smaller than expected, the sample size may not have been sufficient for testing differences of these measures. Post-hoc power analysis revealed a power value of 0.50 based on the experimental effect size. Increasing the complexity of the task could increase the effect size, thus allowing additional differences to be found significant. Regarding hit rate, the sample size for the current study was sufficient (post-hoc power was 0.90).

Other limitations were in the feedback setting design. Not all feedback modes were tested individually, nor were all possible feedback combinations tested. Additionally, the specific feedback modes were set to the default settings throughout the entire study. The handheld scanner was set to a vibrate duration of 200 milliseconds, LED light duration of 1000 milliseconds, and a sound duration of 80 milliseconds. These

settings could be adjusted. It is unknown whether or not the duration of certain settings affects how operators perform.

The participants were limited to using only one scanner – the Intermec SF61B. While this is a scanner used in some distribution centers while scanning incoming packages, that it not the case for all industries and locations. Different scanners have different settings, as well as different locations for lights and speakers. The lights could be placed differently on another scanner, causing the participants to pay more attention to it than they did with the Intermec SF61B. Other scanners also have screens to read whether or not a package has been scanned, and this one does not.

5.3 Future Work

In the future, research can be conducted on each individual feedback mode as well as all the combinations of feedback modes for this device. Tests could also be done on the settings of the different modes (i.e. flashing lights instead of static lights, color, duration of auditory signal, duration of vibration, etc.). A different scanner could be tested to see if the same results occur when the location of certain modes (e.g. speakers, lights) changes. This test could also be done on real operators within a distribution center over an entire work shift to see if that effects the results at all.

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APPENDIX A

PARTICIPANT MATERIALS

A.1 Demographics Survey

1. What is your age? _____

2. What is your gender?

   A. Male B. Female

3. Do you have hearing problems?

   A. Yes B. No

4. Have you ever had nerve damage in your hands or fingers?

   A. Yes B. No

5. Which of the following best describes your eyesight?

   A. 20/20

   B. 20/20 corrected with glasses

   C. 20/20 corrected with contact lenses

   D. Less than 20/20

6. Do you have any type of color blindness?

   A. Yes B. No

7. Have you ever been employed in a job that requires product barcode scanning (or similar)? Example jobs include warehouse operator, package handler, retail store clerk, grocery store checker, etc.

   A. Yes B. No

      a. If yes , please describe your job:

      b. If yes, please list the approximate length of time you were employed in that job:

8. Do you currently own a cell phone?

   A. Yes B. No

   a. Place an X in the blank that corresponds with the notification you use most for each of the following:

	a. Vibration	b. Audio Tone	c. Visual setting	d. Combination
Phone call				
Text message				
E-mail				
Calendar events/reminders				

A.2 Overall Preference Survey

Please complete this survey to the best of your ability regarding the tasks previously completed.

1. Rank the feedback modes in the order in which you relied on them.

____ Auditory

____ Visual

____ Tactile

Please rate each statement on a scale from 1 to 5. Consider the feedback modes used by the handheld wand scanning device while scanning the boxes.	Strongly Disagree				Strongly Agree
2. I could clearly hear the beep.	1	2	3	4	5
3. I could clearly see the green light.	1	2	3	4	5
4. I could clearly feel the vibration.	1	2	3	4	5
5. The auditory feedback was useful while scanning boxes.	1	2	3	4	5
6. The tactile feedback was useful while scanning boxes.	1	2	3	4	5
7. The visual feedback was useful while scanning boxes.	1	2	3	4	5
8. The combination of more than one feedback was useful.	1	2	3	4	5

9. On a scale of 1 to 5, how stressful did you find these tasks?

Not Very Stressful				Very Stressful
1	2	3	4	5

10. Of all four trials, which feedback mode did you find most useful?

A. Auditory

B. Auditory plus Visual

C. Auditory plus Tactile

D. Auditory plus Visual plus Tactile

11. Why did you find this setting most useful?

12. Is there any other setting or combination of settings you think you would find more useful over this one?

A.3 Job Scenario

Box Scanning Task

You work for FedEx in a distribution hub located in Memphis, TN. Your job is to scan boxes and put them on a truck to be shipped. Today, you are scanning boxes that are being shipped to Atlanta. When a box scans, you place it on the truck to be shipped to its destination. When a box does not scan, the box is in the wrong place and is not to be shipped to Atlanta. In this case, you place the box on a conveyor to be sent back through sorting.

Your work day starts now!

APPENDIX B

PROCEDURE MATERIALS

Figure B.1 Barcode 39: Incorrect Scans

Figure B.2 Barcode 128-Correct Scans

Figure B.3 Table Label for Top of Table

Figure B.4Table Label for Underneath Table

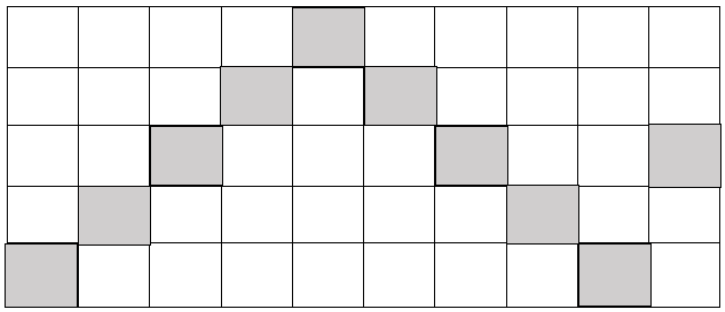

Figure B.6 Box Stacking Order for Feedback 1

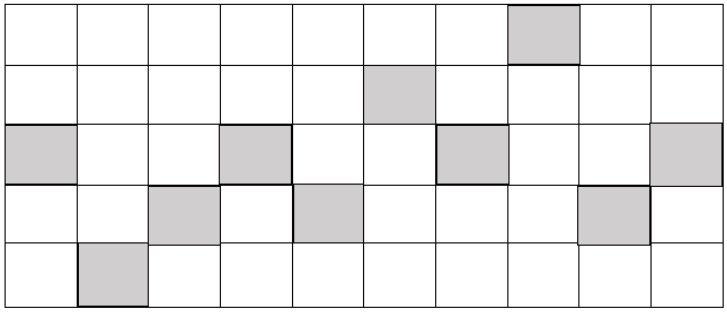

Figure B.7 Box Stacking Order for Feedback 2

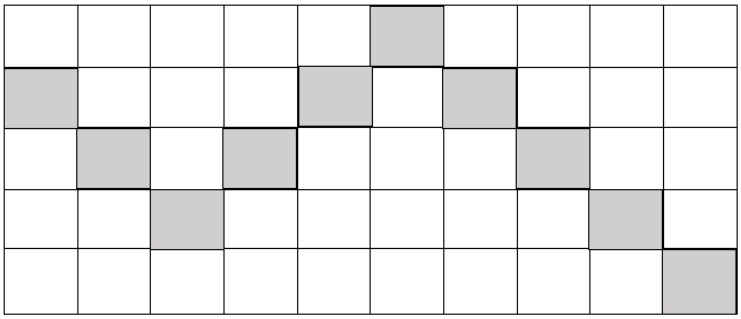

Figure B.8 Box Stacking Order for Feedback 3

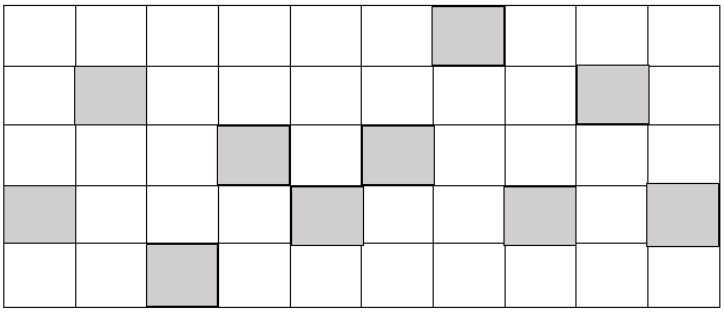

Figure B.9 Box Stacking Order for Feedback 4