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As miners are expected to wear more and more equipment, space and capacity on their mining belt is becoming scarce. To combat this, several companies have recently developed vests for mining. We explored the usability, acceptance, and performance of one of the mining vests through a field evaluation. A total of 18 miners across various positions were recruited from high and med/low seam underground coal mines to wear a mining vest over a six-week period. Results confirm that comfort, especially related to overhead work, was a key factor to the usability of the vests, and comfort was a bigger factor in the lower seam mine than the higher. Reports of various other factors are included in this publication. Despite other concerns, the miners remained positive and interested in the concept of a mining vest, especially for certain occupations. With some modification, the mining vest could be an effective way to house the necessary equipment traditionally worn on a belt.

INTRODUCTION

Spurred by recent mining disasters (Sago, Darby, Crandall Canyon, and Upper Big Branch) (Gates et al., 2007; Light et al., 2007; United Mine Works of America, 2006, 2010), legislation (*Mine Improvement and New Emergency Response Act of 2006*, 2006), and heath initiatives (End Black Lung – Act Now) (Mine Safety and Health Administration, 2013a), U.S. underground coal miners are required to carry an increasing amount of equipment. Miners typically wear between eight and twenty-two pounds of personal protective equipment, not including the tools they need to actually perform their jobs. Currently, most personnel in underground mines use a mining belt to carry their equipment. However, this design provides limited space to attach heavy and bulky equipment, and with pieces like the self-contained self-rescuer (SCSR - 5.9 lbs.), required to be worn or kept within 25 feet, and the personal dust monitor (PDM - 6.6 lbs.), which may be required in the near future, the space and carrying capacity can be exceeded very quickly.

To address this problem several companies have recently developed vests for mining. Similar in form and function to tactical vests police officers wear and load-bearing vests used throughout the military, the mining vests were designed to help the miners carry their equipment. However, the population of the mining industry varies from those in law enforcement and the military. Mine workers tend to be older than those in the military. A recent survey of coal miners found that the average age was 43.8 years old (McWilliams, Lenart, Lancaster, & Zeiner, 2012), while the average age of active duty military personnel is only 28.6 years old (Office of the Deputy Under Secretary of Defense, 2012). Mine workers also are not required to maintain an elevated level of fitness as in the military and some law enforcement agencies (Department for Homeland Security, 2013; Department of the Army, 2011) and yet they are required to carry weights similar to the law enforcement duty belt/vest (10 to 20 lbs. – not including body armor) (Blackhawk Products Group, 2010) and between 20 and 40% of the fighting carry load for the military (Polcyn et al., 2002).

Underground mining also differs from other industrial groups in the types of tasks performed. Due to the space constraints and tasks unique to mining, mine workers spend much of their time bending over, squatting, crawling, twisting, and navigating small spaces. The extent of these postures is mainly related to the roof or seam height of the work environment, where in extreme cases miners work in average seam heights as low as 26 inches and lower in certain areas (Mine Safety and Health Administration, 2013b).

It is still largely unknown how the unique aspects of the mining environment affect the usability of new equipment, because of the limited feedback obtained from the industry. Currently, most mining products have to meet few if any standards for wearability or usability. The end user, the mine worker, is often not asked for his or her input on comfort or wearability until after the product has been engineered. This lack of feedback can create a conflict between the usefulness of the product and whether the mine worker will actually wear it or how effectively the mine worker will be able to perform his or her job while wearing it. Interviews with mine workers who were asked to wear the PDM revealed this conflict. The miners found the information the PDM provided about their exposure to respirable dust to be valuable; however, the miners still resisted wearing the device because it was not comfortable (Peters, Vaught, Hall, & Volkwein, 2008). Without user feedback, it remains unclear whether the currently available vest designs will be suitable for mine workers.

In this research study, we explore the usability of a mining vest through field evaluation. We aim to better understand how a vest will be used in the mining environment and what barriers exist to its acceptance in underground mining. Both high-seam (roof height of ≥61”) and medium to low-seam (roof height of ≤60”) coal mines were targeted to ensure that the differing limitations of roof height were addressed (Peters, Fotta, & Mallett, 2001).

METHODS

Subjects

Nine participants at two Eastern Pennsylvania coal mines (18 males) were recruited to participate in this study. One mine was a high seam mine and the other was a med/low seam mine. Both mines operated two continuous mining machines on one section per shift. The participants at both mines were a mix of various positions whose work location was primarily underground (continuous miner operator [CM], shuttle car driver, belt man, mechanic, utility man, fire boss, roof bolt operator, and foreman). The miners were recruited from all three nine-hour shifts, where the first and second shift were production and rotated every two weeks and the third shift was maintenance. The participant demographic data can be found in Table 1. Informed consent was obtained prior to participation, and the protocol was approved by the National Institute for Occupational Safety and Health human subjects review board.

Table 1: Participant demographic information

ID	Mine*	Position	pExp† [yrs]	mExp [yrs]	Age [yrs]	Height [in]	Weight [lbs]
V01	L	CM	1	5.5	25	73	170
V02	L	Shuttle	2	2	38	69	200
V03	L	Belt	2	8	49	66	165
V04	L	Mechanic	3	3	41	72	211
V05	L	Bolter	2.5	2.5	44	73	190
V06	L	Utility	1	3	28	69	165
V08	L	Fire Boss	5	>25	52	67	175
V09	L	Bolter	1.5	2	21	70	200
V20	L	CM	1	3	35	71	210
V10	H	Bolter	1.33	1.66	31	68	165
V11	H	Foreman	8	25	46	72	200
V12	H	Bolter	1	2	21	72	190
V13	H	Fire Boss	1.5	>10	55	72	210
V14	H	Foreman	1	31	54	65	155
V16	H	Mechanic	1	1	31	65	140
V17	H	Shuttle	0.5	15	55	71	220
V18	H	CM	1	5	41	70	175
V19	H	Belt	25	25	46	70	185

* L-Medium/Low Seam; H-High Seam
† pExp-Experience in current position; mExp-Total Mining Experience

Mining Vest Modification

Each participant was given a vest and a set of five movable pouches to be worn over a six-week testing period. The vest was one of the commercially available mining vests with modular attachment mechanism similar to the pouch attachment ladder system (PALS) used by the military that had been modified slightly. Several loops were removed to prevent snagging or catching on machinery. The reflectivity of the vest was also increased by the addition of 1-1/2-inch strips of reflective material to the pouches as well as the back of the mining vest. These modifications were done at the request of the mines' safety staff.

Experimental Design and Protocol

As a pre-/post-comparison with two groups (mine type), the participants were asked to wear a mining vest as much as possible over a six-week period. During the six-week period, the participants were also instructed to document use and feedback about the vest weekly in a diary. Demographic and preference data were collected from each participant before and after the vest intervention via a paper and pencil questionnaire.

As part of a larger research questionnaire, the participants were asked how they felt about a mining vest in general, if they would use one, and if it would change how they performed their job. The participants were also asked questions specific to the vest they were given (Table 2). Each question was administered on a 10-point Likert scale from 1 to 10, where 1 was poor and 10 was excellent for questions 1 to 3, and 1 was extremely unlikely and 10 was extremely likely for questions 4 to 7. Both sets of questions were administered before and after the six-week testing period.

Table 2: Pre/post questions - specific mining vest

	On a scale from 1 to 10…
1	…please rate the [mining vest you were given] OVERALL
2	…please rate the COMFORT of the [mining vest you were given]
3	…please rate the USEFULNESS of the [mining vest you were given]
	How likely is it …
4	…that you would wear the [mining vest you were given] consistently day in and day out (would wear it at all)?
5	…that you would wear the [mining vest you were given] for the majority of a shift underground (would keep it on)?
6	…that you would recommend the [mining vest you were given] to other miners that you work with?
7	…that the [mining vest you were given] would make your job easier?

NOTE: reference to the specific vest was removed

The ratings between time points (pre- and post-) and in between mine groups (med/low and high) were compared using a repeated measures ANOVA. The pre- and post-means where also compared to neutral (5.5) using parametric t-tests and nonparametric Wilcoxon sign rank tests where appropriate. Additional post-hoc independent t-tests were performed between mine groups for all of the ratings to examine the interaction of time and mine.

RESULTS

Out of all 18 participants only six said they would continue using the given mining vest after the six-week period (V01, V06, V11, V13, V18, V19), but only three of those said they would wear the vest regularly (V01, V13, V19). The main complaints were that the shoulder straps were very uncomfortable, the vest rode up, the vest was too hot, the vest was not flexible enough, and the pouches did not fit the equipment. However, at the post-test, 17 out of 18 miners said that they still liked the idea of a mining vest and would be willing to try a different one.

The ratings of the specific mining vest showed that there was no main effect for the mine type, but the ratings significantly decreased for the overall rating, comfort rating, overall use likelihood, shift use likelihood, and the ease of use of the vest (Table 3). The ratings also were trending towards a significant interaction effect between time and mine, indicating group differences between the mines at either the pre- or the post-testing visit.

Table 3: ANOVA results of specific mining vest ratings

Question		Mine	Time	Time x Mine
1	**Overall Rating**	0.579	0.045*	0.414
2	**Comfort Rating**	0.434	0.016*	0.299
3	**Usefulness Rating**	0.884	0.362	0.723
4	**Overall Use Likelihood**	0.511	0.001*	0.061
5	**Shift Use Likelihood**	0.532	0.015*	0.064
6	**Recommend Likelihood**	0.490	0.277	0.671
7	**Ease of Use**	0.148	0.007*	0.064

* Significance at $\alpha \leq 0.05$

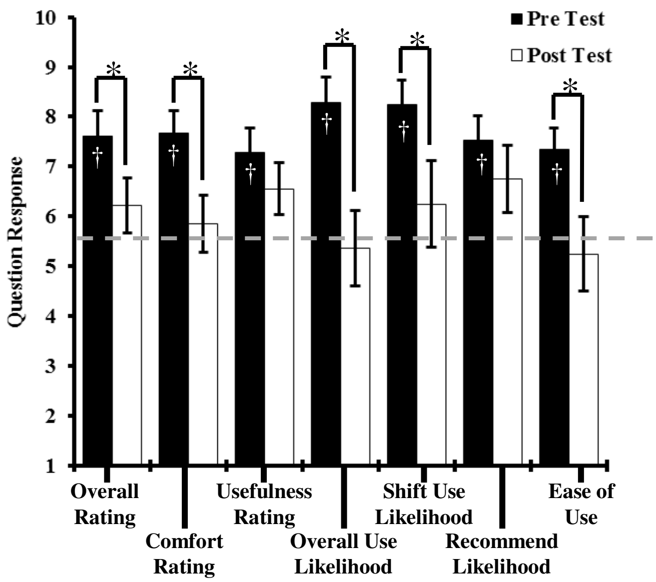

Figure 1: Pre- and post-testing across subject averages for the specific mining vest questions. Values are presented in order of questions listed in Table 2. The values were recorded on a one to ten Likert scale, where ten was the highest and one was the lowest. The gray dotted line indicates neutral at 5.5. Significant differences between pre- and post-testing are detnoted by * and significant differences between neutral are denoted by † ($\alpha \leq 0.05$). Error bars represent ± 1 standard error.

In the pre-test, the across-subject averages for all of the ratings were significantly positive (>5.5) with p-values of 0.005, 0.002, 0.006, 0.001, 0.001, 0.001, and 0.001 for questions 1 through 7, respectively (black bars in Figure 1). There were no significant differences in the pre-responses between mines. The post-test across subject averages were not significantly different from neutral in either direction. However, the usefulness rating (question 3; p-value = 0.058) and recommendation likelihood (question 6; p-value = 0.080) were trending towards positive (white bars in Figure 1) and were not significantly different from the pre-test values. All other questions had significantly lower results (Figure 1).

Examining the post-test results in groups revealed differences between mines (Figure 2). The miners from the med/low seam mine on average said they were less likely to wear the vest (Overall Use Likelihood; question 4) and less likely to keep it on (Shift Use Likelihood; question 5). Furthermore, the med/low seam group's ratings were significantly lower than those of the high seam group for ease of use of the vest (question 7; p-value = 0.046). The ease of use of the vest, question 7, for the med/low seam mine was also rated on average significantly lower that neutral (5.5) (p-value = 0.040).

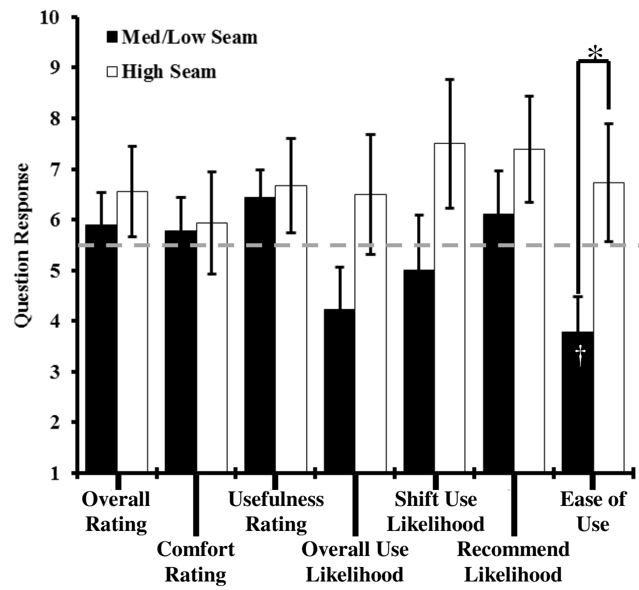

Figure 2: Across subject means of post-test values by mine for the specific mining vest questions. Values are presented in order of questions listed in Table 2. The values were recorded on a one to ten Likert scale, where ten was the highest and one was the lowest.The gray dotted line indicates neutral at 5.5. Significant differences between pre- and post-testing are detnoted by * and significant differences between neutral are denoted by † ($\alpha \leq 0.05$). Error bars represent ±1 standard error.

DISCUSSION

The initial homogeneity of the groups and the initial positive outlook coupled with willingness to try another version of the mining vest in the future (17 of the 18 indicated this during the post-test) suggests that a mining vest could be a viable alternative or supplement to the mining belt. On the pre-test questionnaire, across seam heights and job positions there were no outlying negative responses. The vest was something that all the miners were interested in trying and willing to give a fair chance. However, the reduction in the ratings across the board is an indication that this version of this particular vest is not the most usable solution. Two-thirds of the miners did not make it through the six weeks, and only three miners wanted to continue to use it regularly.

The continued interest in the mining vest was related to several features, namely (1) the increased carrying space, (2) the modularity, and (3) the redistribution of weight. Items that miners had previously carried in the front of their coveralls now could be held within a pouch or on a hook. The mining vest provided more real estate to attach their tools and instruments. The modularity of the vest was also an important feature among the miners. Each miner could setup the vest how he wanted, providing accommodation for different job titles, right or left handedness, and personal preference. Additionally, a feature that was important to some of the miners was the redistribution of weight off the hips. The mining vest provided an alternative loading method to those miners who walked a lot or had hip problems that made wearing a belt difficult. However, biomechanical studies should be performed to ensure the positive effects of this weight redistribution in the long term.

Comfort was the main concern expressed in the rating responses and open-ended feedback. As a whole, the miners were interested in a vest that fits better, moves with them, and is not a burden during their overhead work. The miners disliked (1) the shoulder material and dimensions, (2) the overall fit, (3) the lack of waist/hip anchor, (4) the increased thermal resistance of the vest, and (5) the pouch sizing. Having a sizing mechanism in the shoulders that used multiple layers of hook and loop added too much rigidity across and over the shoulders, preventing the vest from moving with the miners. The rigidity of the shoulder straps also made shoulder width a factor, because the straps dug into miners' necks while performing upper body movements and especially during overhead work. Though our sample size was not large enough to examine the effects of position, it is interesting to note that not a single roof bolter operator continued to use the vest, as roof bolting involves a large amount of overhead work and twisting. Furthermore, of the miners who continued to wear the vest regularly, two of three were from the high seam mine and held positions that required only limited overhead work. Contrary to typical load-bearing vest designs, the hook and loop sizing component in the shoulder makes it undesirable to increase the shoulder strap width to distribute the load. It may be necessary to change the width of the shoulder straps as well as the materials used, if not change the sizing mechanism altogether. The sizing components of the rest of the vest did not appear to meet the expectations of the miners either. Miners had problems with the vest riding up, as well as being too loose around the upper torso where no adjustment points existed. Perhaps the availability of sizes and the addition of a waist/hip anchor would mitigate this. (Note: There were loops that were designed to attach to a belt. However, these were removed because they were not big enough to be compatible with a 3-inch mining belt, posed a snagging hazard, and were requested to be removed by the mine's safety management.) The reduced ability to dissipate heat also appeared to be an undesirable feature of the vest as many miners found the vest too hot to wear while working. While heat management can be achieved by the removal of other layers, this is often not possible (there are none to remove) or inappropriate (skin protection is required). A mining vest should balance durability and versatility with area coverage to minimize added thermal and evaporative resistance while still maintaining functionality. Lastly, the poor fit of the pouches was also a problem for the miners. Most of the pouches sold with the mining vest were designed to hold a single instrument/device (i.e. self-contained self-rescuer, radio, etc.), but they were made to fit the biggest product on the market, which were not the products used at these mines. This design strategy was problematic because the pouches were way too big for the devices actually used by these miners. Therefore, the pouches leaned away from the miner's body, making them harder to wear, more prone to catching and snagging, and allowing some of devices to fall out. Additional product specific pouches would help eliminate this problem.

Furthermore, the negative features may be more critical in lower seam heights. It is hard enough for the miner to stoop, crawl, and lay down all day, and the vest design does not make it any easier. Likewise, the med/low seam miners rated the vest significantly lower than the high seam miners in ease of use (question 7). The reduction in ease of use/added burden may be due to the fact that in lower seam heights miners tend to lean forward more. With an increased amount of equipment in the chest area as compared to the belt area, the equipment can get in a miner's way when hanging loosely at the chest level. If the vest were more form fitting, and the pouches fit the equipment better, this problem could be mitigated. Nonetheless, the trending towards significance of the interaction effect for overall use likelihood and shift use likelihood (questions 4 and 5) implies that after the trial period the med/low seam miners were less likely to use the vest. Though this effect was not significant at the 95% confidence level, it still shows importance since the sample size was small. As predicted, lower seam height amplifies the comfort and usability problems.

Overall, the majority of the negative feedback about the vest was related to its wearability and comfort, but despite the negative feedback on the specific vest design, the miners appear to still be interested in a mining vest. All but one miner explicitly said so. Based on the unchanged usefulness and recommendation ratings, they saw value in the vest as well. The feedback from the miners provided valuable input to the cost benefit of utility versus comfort and will play an important role in the improvement of the vest design. From the development of the study and the feedback received here, we believe that the following criteria should be incorporated into future mining vest designs

- Flexible shoulder straps (no rigidity)
- A waist/hip anchor
- Form fitting design across sizes
- Durable construction
- Breathable material
- Modular configuration of pouches
- Equipment specific pouches
- Retro-reflective material

Limitations & Future Work

As previously mentioned a limitation to this study was the small sample size and the mine operator and location. Both mines used for subject recruitment were small mines in the Eastern Pennsylvania coal region run by the same operator. Size, regional, and company differences may occur. We recommend that future work be conducted to examine these possible differences. Future work in the placement of equipment over various position-specific tasks should also be completed to ensure that the possible designs are biomechanically sound and address the needs of the many different job titles. Future designs may include a combination of a vest and a belt in order to keep the vest anchored at the waist.

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