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Protective Clothing for Pesticide Applicators: A Multimethod Needs Assessment

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ABSTRACT

Protective clothing is an important line of defense for workers in hazardous occupations. Even though workers generally recognize the need for protective clothing, they often experience problems with the sizing, design, and function of the clothing as well as experiencing discomfort. As noted by Eiser (1988) among others, objections can be sufficiently strong that workers may not wear the clothing properly or at all. Even when garments are worn as recommended, design flaws may result in problems that expose workers to environmental hazards.

The purpose of this project is to conduct a multimethod field analysis on one type of protective garment and to determine what design modifications might improve that garment. The garment selected was the coverall due to its extensive use for a variety of hazardous activities such as asbestos abatement, clean room work, and pesticide application by agricultural workers. Since features desired in protective clothing may vary from occupation to occupation, the users chosen for this study were pesticide applicators, although the literature on coveralls for other occupations was reviewed for general information.

Keywords: Assessment, analysis, protective clothing, modifications

Studies of Coverall Function and Design

Mobility or range of motion and the related concept of stress points have been common dependent variables in studies of protective coveralls. Work in this area includes studies by Crow and Dewar (1986), Ashdown and Watkins (1992), Adams and Keyserling (1995), Huck and Kim (1997), and Huck, Maganga, and Kim (1997).

Crow and Dewar (1986) used rubber sheeting with horizontal and vertical slits to determine areas of stress in combat coveralls as well as shirts and trousers. In this case, the goal was to determine minimum seam strength requirements rather than to redesign the garments. A subsequent study by Ashdown and Watkins (1992) used the same methodology to improve the design of coveralls used by asbestos abatement workers by incorporating extra fabric in those areas that showed signs of stress. Those areas were the back of the sleeve armscye, the wrist, the back of the torso, the knee area at the inseam, the front of the leg and foot, and the back of the hood. Both a movement analysis test and a field test involving subjective evaluations of the original and new coverall indicated that the redesigned coverall increased mobility.

Two studies by Huck (Huck & Kim, 1997; Huck, Maganga, & Kim, 1997) also looked at the effects of adding ease on range of motion measures and assessed subjective perceptions of fit, comfort and mobility. Again, adding ease in targeted areas was found to result in improved mobility as well as more positive subjective evaluations of the coveralls. However, Huck et al. added a cautionary note that adding ease in one area, while increasing mobility in that area, may actually cause a decrease in other areas. In work by van Schoor (1989), the effect of ease on perceptions of fit and overall comfort was studied. An activity analysis was conducted to select typical applicator movements. The movements identified were stepping up onto a tractor, turning while sitting in a tractor seat, reaching up over a tank, crouching to look at a nozzle, and reaching up to a boom. The actions of donning and doffing the coverall were also included in this study. Results indicated that changes in the amount of ease produced significant differences in the individual aspects of functional fit but did not influence overall comfort ratings.

Adams and Keyserling (1995) considered the effect of fabric weight as well as fit on mobility. Fabric weight was found to affect mobility but less so than garment size. A related paper by Adams and Keyserling (1996) described a study comparing different methods of measuring mobility.

Other coverall studies have investigated the relationship between suit ventilation and physiological and thermal strain (Holmer, Nilsson, Rissanen, Hirata & Smolander, 1992; Turpin-Legendre & Meyer, 2003; Turpin-Legendre & Meyer, 2007). Holmer et al. compared three different types of protective coveralls for asbestos workers – Tyvek, polypropylene and GoreTex. At 25° C, responses among the suits were similar. However, at 36° C, there was significantly higher thermal strain in the Tyvek suit (the suit with the highest resistance to water vapor and the lowest air permeability). The studies by Turpin-Legendre and Meyer compared ventilated with non-ventilated coveralls in a field study (2003) and again in a laboratory study (2007). In the field study, there were only a few differences between the ventilated and non-ventilated coveralls on measures of physiological strain; there were more significant differences in the subjective measures. In the laboratory study, the only physiological difference between the ventilated and non-ventilated coverall was that sweat losses were significantly higher in the Tyvek suit. On the other hand, the ventilated suit was rated as more cumbersome.

Although restrictions on mobility and thermal stress are obviously key problem areas to be addressed in development of improved protective clothing designs, worker acceptance and satisfaction are apt to be influenced by a variety of other clothing characteristics as well. Therefore, the present study was designed to capture a comprehensive picture of positive and negative attributes of pesticide protective coveralls currently on the market than has been provided by earlier, more focused studies of protective coveralls. First questionnaire and interview formats were used to elicit information on worker usage and practice regarding protective coveralls. Then, in order to better understand restrictions in mobility, problems with tears in the coveralls, and issues regarding wearing practices and donning issues, a photographic record was made of each participant wearing their equipment and demonstrating working positions related to their job. These types of data should be useful to designers who need an understanding of the entire pesticide application system to generate integrated design solutions. Scholars such as Rosenblad-Wallin (1985) and Ariyatum, Holland, Harrison and Kazi (2005) have noted the advantages of starting the design process with the user in the use situation and the disadvantages of ignoring consumers' latent needs.

Method

Research Instrument Development

To capture as complete an understanding as possible of the context in which pesticide protective coveralls are used, a multimethod approach was taken to both record user issues and functional limits to the coverall performance in the field. A questionnaire was developed to obtain basic objective information including demographic data as well as data related to use of pesticides and protective clothing. A follow-up interview was designed to gain more in-depth information about preferences, problems and practices of the applicators. A set of photographs taken of the users provided a visual record of wearing practices, size and fit issues, common working positions, and stress areas visible in the coveralls. The range and variety of working positions recorded in the study can provide visual images with data for assessing the issues with current coverall styles in actual working conditions. Participants in the study were therefore asked to don their protective garments and show how they adjusted those garments before coming in contact with pesticides. The pictures taken of the applicators in working positions supplemented the questionnaire and interview data.

Sample Selection

The researchers contacted local organizations and units that could be expected to employ pesticide applicators. Contacts included university departments engaged in greenhouse and field work, commercial pesticide application companies, and managers of golf courses.

Results and Discussion

Questionnaires and Interviews

A total of 40 pesticide applicators from New York and 23 from California agreed to participate in the study. The majority of the 63 respondents reported wearing disposable coveralls during the course of pesticide application; the six people who did not report any use of disposables were eliminated from subsequent analyses, leaving 57 respondents. The demographic data indicated that most of the respondents (84%) were male. The mean age of the sample was 38; the age range was 19 to 58. Age groups were fairly evenly represented with 19% (11) between 19 and 29, 33% (19) between 30 and 39, 30% (17) between 40 and 49, and 18% (10) between 50 and 58. Mean values of self-reported height and weight were 70 inches (with a range of 60 to 76) and 186 pounds (with a range of 118 to 270) respectively. For the 52 respondents who reported both height and weight, the average body mass index (BMI) was 26.2. The range of BMI values was from 20.2 to 36.6. Eighteen participants (35%) were normal weight (18.5-24.9 BMI), 26 participants (50%) were overweight (25-29.9 BMI), and eight participants (15%) were obese (greater than 30 BMI).

As can be seen in Table 1, the most common dress for work was a knit shirt (72%) and jeans (77%). Protective clothing was then worn on top of these work clothes. When designing protective coveralls, it is important to determine what additional gear will be worn with the coveralls in order to understand the interface between clothing and equipment (see Table 2). In this sample, gloves were most often mentioned (91%), followed by boots (67%). Of course, the designer also needs to know how these items are worn with the coveralls. Data from the interviews on donning and wearing procedures suggest a relatively even division between wearing sleeves over gloves (30%) and tucking the sleeves into the gloves (28%). Regarding boots, however, most respondents stated that they wore their pant legs over their boots (47%). Also, 21% of the respondents used tape or rubber bands to secure the pant leg to the boot. This has the effect of tethering the pant leg to the boot restricting mobility if the pant leg is not long enough. This modification also suggests user concern about gaps between coveralls and boots; without tight connections between parts of the clothing system, as noted by Down (2002), there is apt to be pesticide leakage at the interfaces. The use of hoods and the addition of aprons to the protective clothing ensemble also need to be considered; as shown in Table 2, these were mentioned by 32% and 25% of the respondents, respectively. The protective garment must be designed with these items in mind to prevent restriction of mobility and other user problems in the interface with the garment.

Table 1: Work Clothing and Protective Clothing Worn by the Applicators

Responses N=57	Number	%
Clothing typically worn to work		
Shirts		
Knit shirt	41	72
Woven shirt	18	32
Other shirt	15	26
Pants		
Blue jeans	44	77
Other pants	15	27
Overalls	3	5
Uses protective clothing	57	100
Characteristics of protective clothing worn		
Waterproof	29	51
Breathable		
No	27	47
Yes	24	42
No answer	6	11

Table 2: Supplementary Protective Gear

Responses N=57	Number	%
Supplementary gear worn		
Gloves	51	91
Boots	38	67
Hood	18	32
Apron	14	25
Shoe covers	11	19
Interface of clothing and gear		
Wear sleeves over gloves	17	30
Tuck sleeves into gloves	16	28
Wear pant legs over boots	27	47
Tuck pant legs into boots	2	4
Tape/rubber band cuffs or pant legs	12	21

When users engage in a large variety of work activities while wearing the coveralls, this is apt to add to the complexity of the design process. In addition to applying the pesticide (77%), the applicators reported wearing protective coveralls to mix the pesticide ingredients (74%), load the application equipment (67%), and clean the equipment (67%). The pesticide formulations and equipment used also showed considerable variability, with 7 different primary equipment types and 11 different pesticide formulations (see Table 3).

Table 3: Work Activities

Responses N=57	Number	%
Actions performed in coveralls		
Apply pesticides/chemicals	44	77
Mix pesticides/chemicals	42	74
Load applicator	38	67
Cleaning equipment	38	67
Transport or retrieve pesticides	23	40
Type of equipment used to apply pesticides		
Hand-operated sprayer	31	54
Boom sprayer	21	37
Air-blast sprayer	11	19
Hydraulic sprayer	8	14
Mist blower	7	12
Duster or Fogger	6	10
Other	4	7
Type of pesticide formulation used		
Soluble powder	40	70
Flowable	39	68

Wettable powder	37	65
Emulsifiable concentrate	36	63
Dry flowable	29	51
Granule	29	51
Bait	13	23
Dust	12	21
Ultra-low volume concentrates	10	18
Aerosol	9	16
Encapsulated	9	16
Other	2	4

The relationship between product development issues and perceptions of protection can be inferred from the responses and associated comments in Table 4, compiled from the interviews. Those people who felt very safe in their protective clothing also reported that their skin was fully covered and that they stayed clean. Durability was also associated with safety; obviously, garments that frequently rip and tear cannot be fully protective. In fact, those respondents who reported feeling only somewhat protected noted problems such as suits ripping or tearing easily, moisture penetration, and dirt entering through the collar.

Table 4: Perceived Level of Protection in Coveralls with Associated Reasons

Responses N=57	Number	%
Feel very protected	34	60
Skin is fully covered		
It keeps me clean		
They are durable		
No bad experiences so far		
Feel somewhat protected	22	39
Some disposables allow moisture penetration		
Feel protected from moderately toxic chemicals		
Don extra apron for very hazardous materials		
They provide some abrasion protection		
Suits rip or tear easily		
Dirt comes in around the collar		
They keep pesticide solids off		

Responses to questions about the durability of coveralls (Table 5) revealed that about a third (28%) of the respondents often experienced tears while working. About another third (33%), encountered tears but not very often and about another third (28%) very infrequently encountered tears. Nine percent had never encountered tears. The most common actions causing tears include bending over (21%), stepping up (18%) and catching on objects (26%) or branches (16%). Reaching forward or up (9%) also resulted in tears for some respondents. Locations of the rips or tears (Table 6) were primarily in the crotch or inseam (26%) and the thigh or hip (25%). Tears also occurred in the armpits, back/shoulder and lower leg area (14% each).

Table 5: Durability of Protective Coveralls

Responses N=57	Number	%
Frequency of tears or rips		
Not very often	19	33
Often	16	28
Very infrequently	16	28
Never	5	9
Actions resulting in tears		
Catching on objects in confined space, e.g. greenhouse benches	15	26
Bending over	12	21
Stepping up	10	18
Catching on small objects or branches while spraying	9	16
Reaching forward or up	5	9
Walking with a long stride	2	4
Backpack sprayer slippage causes rip	2	4
Crawling under houses abrades and tears suit	2	4
Fabric weakens after 4 or 5 uses or strong chemical exposure	2	4
Zipping the suit (fabric catches in zipper)	1	2
Pulling suit over boot	1	2
Stooping	1	2
General movement	1	2

Table 6: Location of rips and tears in coveralls

Responses N=57	Number	%
Crotch/inseam	15	26
Thigh or hip	14	25
Armpits	8	14
Back/shoulder	8	14
Bottom pant leg/ankle	8	14
Around zipper	4	7
Waist	3	5
Sleeve	2	4
Chest	2	4
Knees	1	2
Seat	1	2
Elbows	1	2

Responses to the questions about protective clothing likes and dislikes, shown in Tables 7 and 8, support the focus of previous studies on thermal stress and mobility with fit/ease problems related to both restrictions in movement and damage to the garment. Ten of the respondents made specific mention of fit issues – too long, too short, or too tight. As Adams and Keyserling (1995) observed, protective clothing is often available in only a limited number of sizes due to the cost of manufacturing and/or stocking additional sizes. Of course, purchasers are also interested in controlling the costs of the coveralls. However, they may fail to recognize the costs associated with inefficient performance of the job, health problems associated with exposure to hazardous materials and replacement costs for garments that rip and tear at stress points.

Other characteristics most disliked were the fact that the coveralls rip easily (42%), are hot (37%), and do not breathe (26%). On the positive side, the respondents appreciated the fact that the coveralls offer protection (77%), that they are disposable (12%), and lightweight (9%).

Table 7: Characteristics that Applicators Dislike About Their Protective Clothing

Responses N=57	Number	%
Most disliked characteristics		
Rips easily (movement or catching on things)	24	42
Hot	21	37
Does not breathe	15	26
Fit issues	10	18
Too long (3)		
Too small (2)		
Too short in legs and arms (2)		
Torso too short (1)		
Tight through torso and thighs (1)		
Legs taper too much to fit over shoes (1)		
Hard to don/doff	7	12
Not waterproof (soaks through)	6	11
Too baggy/bulky/catch on things	5	9
Zippers rip/stick	4	7
They are stiff, no give for movement	3	5
Other issues mentioned		
Lack fastening at wrists	2	4
White color alarms people	2	4
Stick to underclothing and ride up	1	2
Shift when crawling	1	2
Has no pocket	1	2

Table 8: Characteristics that Applicators Like About Their Protective Clothing

Response N=57	Number	%
That it offers protection	44	77
It is disposable	7	12
It is lightweight	5	9
It offers head protection (those with hoods)	3	5
Keeps dust and dirt off	3	5
Allows ease of movement	2	4
It signals people to stay away	2	3
It is comfortable in the shoulders	1	2
It is light in color to keep me cooler	1	2
It prevents splashes	1	2
It is inexpensive	1	2
It is easy to use	1	2

The comparison of likes and dislikes also supports the point that design solutions that are accepted by everyone are almost impossible to attain. For example, one applicator felt that the white color of coveralls was cooler than darker colors. Another felt that it was important that the white color served as a warning that dangerous chemicals were being used. On the other hand, another applicator felt that alarming people by working in a white suit was a problem.

Image Content Analysis

A total of 228 images of the 63 participants were recorded and analyzed, an average of 3.62 images for each participant in the study. Images were not labeled to correlate with questionnaires, and multiple images were taken of each participant as the goal of capturing images was to record and identify active working positions and visible signs of fit issues such as stress folds in the garments worn. Participants were asked to don their protective clothing just as they would if they were working with pesticides, and to assume the body positions used in their work. Whenever possible, photographs were taken of workers actually working in the field or with the actual spray equipment or tractors used. Photographs were taken from the point of view and angle that showed the areas where stresses were visible on the coveralls, and multiple images were taken of the same position when needed to show the full range of stresses. In order to focus the visual analysis on the coveralls all backgrounds were removed from the photographs so that the body position and the stresses in the coveralls could be clearly seen (see Figure 1). Images were analyzed in a digital format on the computer screen.

Figure 1: Image of worker reaching down with background removed

All participants wore a layer of street clothes under the protective garment. The participants wore their own protective garments and were wearing the best fit and most comfortable available to them in each case. For many of the participants garments were provided by a manager or purchasing agent and they may not have had input into what sizes were available.

A very wide range of different types of protective garments were worn in the photographic series. Most participants wore a white coverall, with a front zipper. Some participants had hoods, some did not. Not all of the participants whose suits had hoods used them. Some of the garments had elastic at the back waist, wrist or ankle and some did not. There were differences in the way that participants wore their protective garments, for example, tucking the pant legs into the boots or the sleeves into the gloves as opposed to wearing them on the outside. All of these differences, however slight, may affect the fit of the garment and should be taken into consideration when analyzing the photograph.

A content analysis was performed on the set of photographs, identifying fit characteristics as dictated by wrinkles showing strain in the fabric as well as areas where there was excess fabric (excess fabric can cause problems as it is a hazard for catching on equipment resulting in tears). Also noted was the type of protective garment worn, how each participant wore the garment (i.e., pants tucked into boots or over boots, etc), and other equipment worn. The 228 images were first sorted based on the activity of the worker. Six (2.6 %) of the images were activities related to donning/doffing the coveralls, and 56 (24.6 %) showed the fit and wearing configuration with the worker in a standing position with arms by their sides. The rest of the images were categorized as: Bent over from waist (41 images, 18.0%), kneeling or crouching (29 images, 12.7 %), arm(s) raised at about shoulder level (39 images, 17.1%), arms raised to head level or above (7 images, 3.1%), leg raised in stepping position (26 images, 11.4%), performing a task (such as filling a canister) in a standing position (18 images, 7.9%), and sitting/driving (6 images, 2.6%).

Male workers accounted for 145 (63.6%) of the images and 22 (9.6 %) were of female workers; in 61 cases (26.8%) gender was not identifiable. Most of the garments in the images were coveralls made of disposable fabrics (198, 86.8%). Within these images 15 different brands and/or styles were distinguished. Five coveralls were identified as made from re-usable fabrics (cotton or cotton/polyester), and 8 protective suits were two piece outfits made from a disposable fabric with a waterproof film. In 91 (39.9 %) of the images the worker wore a coverall with a hood, and 74 (32.5 %) of these workers were actually wearing the hood.

In 67 (29.4 %) of the images the workers wore a respirator with 14(6.1%) worn under the hood and 53 (23.2%) over the hood. Fifteen (6.6%) of the images show the workers wearing a face shield inside the coverall hood, and 88 (38.6 %) show the face shield on top of the hood. The face shield is up in 2 (0.9%) of the images and down in 26 (11.4%) of the images in which the shield is hinged. In one image, the applicator was wearing a helmet with the face shield and the face shield was up. In 75 (32.9 %) of the images the workers are wearing gloves. In images showing the footwear, the pant leg is tucked into the footwear in 17 (7.5 %) images and the pant leg is outside the footwear in 132 (57.9 %) cases. In 22 (9.6 %) images the footwear is a pull-on rubber boot, in 62 (27.2 %) cases a work boot, and in 40 (17.5%) cases a sneaker or shoe.

Excess material can present problems for pesticide applicators as noted above. Excess material was observed in 138 (60.5%) of the images. Data on excess material by body location and dimension are shown in Table 9. Most of the excess material was observed in the torso width (77 cases). The next most prominent area of excess was the torso length (58) followed by leg length (52). Arm length (40) and width (45), and leg width (33) were also frequent areas of excess. Crotch excess was also observed a few times (4 cases).

On the other hand, insufficient material can also be a problem and manifests itself visually in several ways. These include fabric pulls and skin exposure at the wrist and ankle. Pulls or stresses were visible in many of the images. Overall, pulls across the buttocks or thigh could be seen in 11 (4.8 %) of the images and crotch pulls could be seen in 29 (12.7%) of the images. An example of analysis of pulls in the crotch by position of the applicator is presented in Table 10. Generally crotch pulls occurred from the crotch to the knee in kneeling positions (17 cases) and from the crotch to armhole in reaching positions (7 cases).

Table 9: Image analysis – Excess Material by Body Location and Dimension

Body Location	Dimension		
	Length	Width	Not Specified
Excess – general	-	-	3
Arm	40	45	-
Leg	52	33	-
Torso	58	77	-
Hood	-	-	1
Crotch	-	-	4

Table 10: Image Analysis - Crotch Pulls by Direction of Pull and Position of Applicator

Position of Applicator	Direction of pull		
	At crotch	Crotch to knee	Crotch to armhole
Standing and performing a task (N=18)	4	-	-
Kneeling or crouching (N=29)	-	17	1
Arm(s) at or above shoulder height (N=39)	-	-	7

Some images show that there was not enough fabric in the arm and leg while in the working position. There are 11 (4.8%) images where the arm length is too short and 15 (6.6%) images where the leg is too short for the applicator. In the standing position with arms by the sides, there was only one image that showed that there was need of a longer sleeve. There were no standing positions where the leg length was too short. Areas that are overly tight can interfere with performance of tasks and cause applicator discomfort, as well as contribute to tears in the coveralls. In addition to the pulls from armhole to crotch indicating tightness in that area, there was evidence of tightness in the torso, crotch, and thigh with a too-short torso (25 cases) being the most common problem (Table 11).

Table 11: Image Analysis – Insufficient Material by Body Location and Dimension

Body Location	Dimension		
	Circumference/ width	Length	Not specified
Torso	12	25	-
Crotch	-	-	12
Thigh	-		4

Image Analysis by Position

Understanding the relationship between body position and the fit of the coverall will provide designers with rich information for modification of the current design. Content analysis was used to relate specific actions and interactions with the coverall. Incidental findings (not related to a specific type of activity) can be seen throughout the images such as the adaptation of the suit to hold a set of keys by attaching them with a safety pin. Another participant can be seen reaching within the protective garment (through the zippered opening) to extract something from their street clothes which can be seen underneath. Types of footwear and gloves are also varied and may affect the overall fit and effectiveness of the protective garment.

Donning or Doffing. The first set of photographs showed six participants donning or doffing their protective gear. In four of these photos, the legs of the garments are shown going over the work boots or shoes. The suit legs are often too tight to accommodate putting the shoe through the pant leg as was shown by the strain on the suit even when the toe is angled downwards. The protective garment was being pulled on either by grasping the leg or the body section to force the foot through the leg opening. All of the participants were shown trying to balance themselves when donning or doffing the garment. One photo shows the participant "shrugging" to get the body of the garment over his shoulders after the arms are already encased in the sleeves. Another photo shows the participant modifying the hem of the protective garment by cutting off the narrowest section of the leg to accommodate the work boot.

Bending. This photo set consists of 29 images of participants bending over from the waist. Excess ease is obvious in many of the photos in the length of the sleeves and the bicep width. Some pants have elastic at the leg hem but one that does not has excess length.

Standing. In this set of 32 photos, the participants are in a standing position either directly facing the camera or slightly turned to the left or right. There are a variety of protective suits worn in this photo set and they were analyzed by the style of garment worn.

The first style is a basic jumpsuit style in white with a center zipper and attached hood, though the hood is not always worn. This style is being worn by 27 participants. Four of the participants are female and each of their suits has excess length in the legs, sleeves, torso or all three areas. In three other photos, the participant's sleeves are too short to meet the gloves and approximately two inches of skin is exposed. One participant has tucked his suit into over-the-calf height boots and is wearing thin, tight-fitting rubber gloves. Yet another participant wears elbow length rubber gloves which are too large for them.

Glasses are worn in five of the photos and in one other photo the participant is wearing a full face mask. A respirator is shown in three photos and twice the respirator is secured outside the hood while once it is worn over the hood. One participant is trying to look to the left showing that their vision is impaired by the hood.

One photo shows the participant with pants legs which are too long as is evident by the horizontal wrinkles. This participant is a large person and fills out the torso of the suit, and there are stress wrinkles in the torso area from the neck to the hips. This participant has the hood on and the coverall is not fully zipped.

The second type of suit shown in the standing position is made of a standard twill fabric in dark blue. The garment looks to be too large for the wearer in all major areas of fit. The sleeves hang to the second knuckles and the pant legs have horizontal wrinkles indicating excess length. There are some wrinkles in the crotch area showing sagging on the outseam, specifically wrinkles that angle from the crotch to just above the knee on the outside leg. The sewn shoulder of the garment has fallen off the natural shoulder of the participant.

The third style of suit in this photo set is a white protective garment with no hood attached. In all seven of these photos, the pants legs are on the outside of the boots or shoes and none of them have elastic at the pants hem. Three participants are wearing sneakers that do not cover the ankle and this may result in exposure to pesticide at this interface with the coverall. Three other participants are wearing work boots. Four photos show that there is too much length in the torso and only in one photo are the pants an appropriate length. In one image the pant legs are too long by a few inches, and the sleeves hang to the first knuckle. The sleeves hang to the second knuckle on another wearer. Three images show the workers wearing baseball style caps and a different worker is wearing a respirator with no face or eye shield.

One leg raised. In this set of 27 photos the participants are standing with one leg raised as if stepping up. The legs are in a variety of angles from a few inches off the ground to being raised as high as the participant's hips. Participants are shown from the front, side and back. Overall there are many photos which show the stress at the crotch due to the position. Some show the stress through the back or front of the torso which may indicate that the torso is too short for adequate movement. Some of the pant legs pull upwards on the leg which is lifted. This is problematic when the hem of the street clothes is exposed to contamination. The necklines in some of the photos are pulling back either due to the head or neck being tilted forward or due to the shortness of the torso length. While one photo shows horizontal wrinkles at the mid chest level indicating tightness, eight have excess fullness in the chest area. The photos of six participants show the garment hanging below the crotch level, indicating that it is too long in the torso.

Areas of tension or tightness can also be seen in this set of photos. In six photos tension in the crotch area due to the raised leg and wrinkles are evident from the upper left leg to the upper right leg. Tension can also be seen in the buttock area in five photographs with vertical wrinkles over the buttocks. Wrinkles are also evident in back views on the inseam from buttock to the knee on eight participants. Lastly, minor tension is evident on the outseam of the raised leg from the buttocks to the knees in six photos.

It is to be expected that the garment leg length would change when the participant bends their knee; however on some participants in these photos this difference is extreme. One photograph shows the hem approximately five inches too short, two photographs show an approximate four inch gap and two others show at least a two inch gap.

Standing, reaching forward. The participants in this photo set are standing with either one or both arms raised overhead. No significant areas of tension were observed in these photos. In three of the photos the protective garment looks too large; one is large overall, one is too long in the torso length and one is too wide in the torso.

Sitting / driving. In this set of photos the participant is driving a truck and in all the photos, the fit is sufficient. There are minimal wrinkles when the participant is in the most extreme position of twisting the body to look behind him. There is excess ease in the crotch area.

Bending over from waist. Participants are standing and bending over from the waist to touch the ground or an object lower than waist level. Most do not seem to have a fit issue except in the most extreme position where there is wrinkling in the back over the buttocks to the outseam at the knee and excess fullness at the waist. Four of the photos show strain in the underarm area in the form of wrinkles when the arm is stretching as if to pick something up. Three indicate that when the arms are raised, the torso is too short for the participant. In one photo the torso width is too tight and this may be due to an incorrect size, not solely from the position.

Arms at or above the shoulder level. The positions ranges from having the participant hold their arm directly in front of themselves to reaching up over their heads. Overall the photos show at least some tightness in most of the suits, particularly in the underarm region when the arms are raised, which indicates the need for extra length or room in this area. Some of this tightness extends into the crotch in eight of the photos or over the buttocks in nineteen photos. In seven photographs the sleeves shorten significantly when the arm(s) is raised. Sometimes the legs are significantly shortened when both arms are raised high over the head; this was evident in just four of the photographs. If only one arm was raised, the shortened pant leg would be on the side of the raised arm.

In two photos the participants are plus sized and the arms/legs of the protective garment are too long for them. The cause for this may be the coverall sizing system forcing the participants to wear a larger size due to their girth with the consequences being sleeves and pant legs that are too long. Another participant seems to be wearing a protective garment which is one size too large.

Kneeling or Crouching. There are a total of 31 photos in this set. The position in all of these photos is extreme with one or both knees bent at least 90 degrees and most are bent beyond this. In some of the photos the participant is also reaching for an item either on the floor or directly in front of them at chest level. Similar to the problems seen in the previous photo set where participants raised their legs, seven of the photos in this set show that the pant leg is shortened by two to four inches when the leg(s) is bent.

Thirteen of the photos show the back neckline being pulled down which is most likely due to the shortness of the torso length in this position. In six of these the pulling is extreme (two to four inches). The forward crouch shows that while the torso may be too short along the back of the protective garment, there was excess in the front as was evidenced in eight photographs, all different from the ones showing pulling along the back. Two photos show strain on the hood due to short torso length.

Standing; side or back view. This set has a total of 25 photographs and with two exceptions the participants either have their arms at the sides or close to their sides. The other two participants are holding their arms out in front of themselves to show movement and possible fit issues across the shoulder blades. One of these does indeed have some tightness; the second one only shows minimal wrinkles due to strain. Overall, many of the suits show excess fabric in the length of the sleeves, pant legs and excess width in the torso. None showed any tightness across the back and none showed any shortness in length of either the pant legs or sleeves.

Standing; front or side view. There are a total of 18 photographs in this set, ten of which show the participant performing a task. The tasks range from holding a canister and nozzle (five participants), holding a jug and filling it with water or other clear liquid (two participants) or wearing an apparatus on their back. Some of the participants are just standing and in two photos, one or both of the participant’s arms are raised slightly.

The protective garments in this series show excess ease in one or more areas including the sleeve length and width, pant length and width and/or torso length or width. Overall the wrinkles are numerous but few are due to straining in this particular position and are most likely due to stress folds remaining from previous positions.

Summary

The conclusions from the questionnaires and interviews reinforce other studies identifying thermal comfort and fit as critical areas needing improvement for protective coveralls for agricultural workers. The frequent rips and tears resulting from activities and encounters with objects are another area of concern that can be addressed with improved coverall design and sizing.

Content analysis of the photographs identified stepping, sitting, bending from the waist, reaching out and reaching up, kneeling and couching, and donning and doffing as the active positions that the users felt were commonly used in their work. These activities agree with those identified by van Schoor (1989), and also correspond with the large incidence of tears reported at the crotch, hip, armpits, and back. Overall, 86% of the tears reported correspond with the stresses that were seen in these locations in the photographs of the active positions. A further 14% of tears reported would be consistent with stresses observed in the donning process (see Table 6). The actions causing tear reported by the users also corresponded to these active positions in 53% of the cases. A further 42% of the tears were reported to come from the coverall catching on equipment or branches. Abrasion from equipment or issues with donning accounted for a further 8% of the activities that were cited as causing tears (Table 5).

From an analysis of the photographs it became clear that if the garment "fits" when the participants is standing still in an anthropometric position (a balanced position with legs slightly apart and arms at the sides of the body), it may not "fit" in any one of the number of active positions, particularly the extreme positions of having the arms above the head or the knee or leg at 90 degrees or sharper angles. On the other hand, pant legs that are too long when standing may provide length that is needed when the knee or torso bends. This is also true for the sleeve length.

Overall, there was no consistency in the items that were worn by participants when working in their protective gear. Some participants wore gloves, some did not, some wore sneakers, some wore work boots and others wore rubber boots. Face and eye protection also varied with some wearing protective glasses, some wearing a full face mask and some wearing partial face protection. Some participants wore no face covering. These variations could be due to requirements related to the different types of pesticides used, the different methods of applying the pesticide or merely personal preference. The variations in equipment are necessary to provide appropriate protection for the wearer from a variety of hazardous substances.

Future studies could use this format but more closely link the questionnaires and images in order to analyze worker perception in relation to objective analysis of the fit and function of the coverall. The collection of data on the user body measurements taken over the work clothing that is worn under the coveralls, along with the size and measurements of the coverall worn by the user in the photographs would add to the value of these data. It would also be helpful to have a range of photographs showing a participant wearing the same garment in a number of positions to help locate the exact position for which a garment is deemed "out of fit".

As it stands, this study provides rich information for the designer to improve coverall design. Images showing the variety of body sizes and shapes, and the variety of fits provided by the coveralls are essential tools to help understand how coverall design and modifications in sizing can help provide better protection across the population of users. Understanding the range of movement engaged in by the users also provides information essential to the designer. Overall this method provided a rich set of visual and verbal data that cannot be acquired any other way.

The next step will be to create a coverall design and a sizing system to help solve some of the problems with tearing of the coverall, in order to provide continuous protection for the workers from pesticides. Sizing should be based on the most recent anthropometric data available for the population. Design modifications should concentrate on providing better movement for the arms, underarms, crotch area, and knee without adding excess fabric that is in danger of snagging, causing rips in the coverall. Cost is another important factor.

Any modifications need to stay affordable, for these garments that are designed for a single use. These issues provide a challenge to the functional designer, but, with the information provided from this study, these challenges can be met and better protection for the user can be provided.

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