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# EVALUATION OF FUNCTIONAL FIT AND COMFORT OF CHEMICAL PROTECTIVE GLOVES FOR AGRICULTURAL WORKERS

BY

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## ABSTRACT

**Evaluation of Functional Fit and Comfort of Chemical Protective Gloves for Agricultural Workers**

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Although chemical protective gloves are an agricultural worker's first means of protection against pesticide exposure, a large percentage of farmers do not wear gloves when in direct contact with agrichemicals. Agricultural workers complain that gloves currently available do not fit well, they are uncomfortable to wear and they interfere with fine manipulation.

The purpose of this study was to evaluate the functional fit and comfort of commercially available gloves recommended to agricultural workers who use pesticides, and to investigate the joint effect of polymer type and thickness of glove materials on fit characteristics. An anthropometric approach to the analysis was chosen to investigate possible sizing and design problems related to chemical protective gloves. The two part study consisted of defining the hand dimensions of the user population (Part A) and evaluating the functional fit of four types of gloves currently available to agricultural populations (Part B).

The hand dimensions of 380 farmers throughout Central Alberta were used to define the user population's hand sizes. Based on the findings from the Anthropometric Survey, 38 farmers representative of the user population's hand circumference and length of middle finger participated in the functional fit evaluation. Four test gloves differing in polymer type, thickness and manufacturer were evaluated for functional fit and comfort by each participant.

During the evaluation of the chemical protective gloves (Part B), functional fit and comfort were measured through subjective evaluations of the goodness of fit of the test gloves, as well as participants' rate of performance while completing standardized dexterity tests. The Minnesota Rate of Manipulation Turning Test and the Craik Screw Test were chosen to study the effects of gloves on tasks requiring two handed coordination and relatively fine manipulation of the fingers. Functional fit and comfort ratings were obtained for each type of glove.

Pearson correlations, analysis of variance and Scheffé's multiple comparison test were used in the statistical analysis. Significant differences in functional fit and comfort were found among gloves differing in polymer type, thickness and manufacturer. For fine manipulation, thinner gloves made from flexible polymers were the most acceptable. Of the four types of gloves, Pioneer's 19 mil tripolymer glove was preferred by the majority of the participants. The tight fitting glove was described as flexible, lightweight, and comfortable, and interfered the least with finger dexterity.

Major design and sizing problems were identified in each of the four types of gloves. The quality of fit (static fit) and decrement in performance (dynamic fit) were most important in participants' evaluation of the overall goodness of fit of the gloves. Gloves that fit tightly and enabled participants to complete the dexterity tests at a rate comparable to bare hands received the highest functional fit ratings. To enable agricultural workers to acheive optimum performance while completing fine manipulative tasks, the quality of fit especially in the fingers of the gloves must be improved.

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# I. INTRODUCTION

Pesticide safety is the responsibility of every individual involved in the manufacturing, distribution, and use of agrichemicals. In Canada, the sale and use of pesticides is regulated through legislation. Before being distributed, the products are reviewed by Agriculture Canada for their safety and efficacy; upon acceptance, the products are registered and then sold (Franklin, 1985). The levels of toxicity vary considerably among pesticides, but with appropriate protective items, they can be handled with acceptable levels of exposure.

Safe use of the pesticides, however, often requires the knowledge of experts, trained to handle toxic chemicals. Commercial pesticide applicators must undergo licensing procedures. They are therefore informed of the risk of exposure and of the means to avoid contamination. Agricultural workers, on the other hand, do not need licenses to spray their own fields. Consequently, due to the absence of formal training, they may be unaware of the potential risk of pesticide exposure. To date, the use of protective clothing is not mandatory, thus an agricultural worker's personal safety depends on how the individual chooses to protect him or herself.

Worker exposure to pesticides has been a research topic for a number of years. The hazards related to the use of pesticides depend on many factors such as the level of exposure, the concentration and amount used, the method of handling the application, and the personal protection adopted (Hobbs,1985; Waldron,1985). Following extensive biological monitoring, in vivo investigations and dermal exposure assessments, many studies indicate that the principal route of exposure is through the skin (Moraski & Nielsen,1985; Wolfe, Durham, Armstrong & Wash, 1967). Up to 90% of the worker's total exposure is due to dermal exposure. While mixing, loading and spraying the pesticides, hands alone account for 20% to 97% of the dermal exposure (Bonsall, 1985; Davis et al.1983).

One important factor to consider in reducing agricultural workers' pesticide exposure is the development of chemical resistant, low-cost, comfortable protective clothing. When the appropriate protective gear is worn, potential exposure to the skin can be reduced to minute levels (Orlando, Branson, Ayers & Leavitt, 1981). During the mixing and loading procedures, gloves normally receive 97% of the total body surface contamination (Abbott,1984). Gloves designed to resist pesticides, are therefore required, especially when the user comes in direct contact with pesticide concentrates.

The availability of chemical protective gloves, however, does not necessarily lead to product acceptance. In a survey conducted in 1983, Hussain (1983) found that only 47% of Alberta farmers wore rubber gloves while mixing and loading pesticides into their sprayers. A majority of respondents to a recent survey conducted by the author throughout central Alberta, responded that they wore protective gloves when handling pesticides. Those who wore protective gloves, however, also reported the removal of gloves to open pesticide containers and adjust or clean nozzles. Reasons given for removing or not wearing any gloves are that gloves currently available do not fit well, they are uncomfortable to wear and they interfere with finger manipulation. Similar to the findings of Rucker, Heffner and York (1988), these preliminary findings suggest that the fit of protective gloves should be considered for product improvement.

Ideally, an acceptable glove must provide protection, facilitate dexterity, and be comfortable to wear (Roebuck, Kroemer & Thomson,1975). Protection and comfort, however, work against each other and therefore the design of protective gloves results in a compromise. The optimum glove design should offer maximum safety, and minimize the training necessary to use it successfully (Lyman,1957).

In order to be used successfully, protective gloves must be designed to meet the needs of farmers; they must fit and function with specified limitations before being accepted by the user-population (McConville,1986). Besides being hazardous, gloves that do not fit well can impede a worker's performance. If the discomfort caused by poor fit is great enough, a farmer's natural inclination will be not to wear protective gloves, leaving farmers with no alternative but to risk exposure while handling toxic pesticides bare-handed.

The sizing criteria presently used by glove manufacturers are based on government specifications. Anthropometric surveys from which specifications can be derived need to include hand measurements from a large number of subjects to represent a population. According to McConville (1986) and Roebuck et al. (1975) data bases that include detailed measurements of men's hands are available primarily from the United States Army . The specifications adopted for designing gloves are therefore representative of the hand measurements of United States military personnel.

Many considerations go into the design of functional clothing. One important factor to consider is the population for whom the functional apparel is being designed. When developing protective clothing, Roebuck et al. (1975) and Pheasant (1986) stress the importance of identifying the potential users and knowing their body measurements. There are wide differences in body dimensions between genders and among groups that have different ages, ethnic backgrounds and occupations. The size range and proportions of manual workers such as steel workers for example, are usually much larger than those of medical doctors and college professors (VanCott, 1972). To meet the needs of a specific population, a designer must therefore know the range of sizes of potential users.

## Statement of the Problem

Anthropometric consideration in the design of protective clothing has been a concern in developing items that fit to maximize a worker's comfort and performance

(Robinette, 1986; McConville,1986; Roebuck et al., 1975). An anthropometric fit test is one approach to successful design of functional clothing. Fit evaluations are particularly important in the early and final stages of the functional design process but also can be valuable once a product has entered the market. A qualitative and quantitative evaluation of the fit of protective apparel by potential users can identify sizing and design problems related to poor acceptance of a product (Van Cott,1972).

The purpose of this study was to evaluate the functional fit and comfort of commercially available protective gloves recommended to agricultural workers who use pesticides, and to investigate the joint effect of polymer type and thickness of glove materials on fit characteristics. The main focus of the study was the relationship between workers' hand sizes and the design of gloves when manipulating agricultural equipment currently being used. Ways to improve glove performance by redesigning nozzles, pesticide containers and other farming equipment were not addressed in this research.

## Justification

To date, there are no available data on agricultural workers' hand measurements. There is also very little work being done with respect to the sizing and design problems of chemical protective gloves used by agricultural workers. Knowing the hand measurements of agricultural workers could be valuable to both designers and manufacturers. Designers could determine more accurately the size criteria to use when developing glove molds and the number of sizes needed to fit the majority of the user-population. Manufacturers could then predict the number of each size they need to produce and keep in stock. From the fit evaluation, the quality of fit of the chemical protective gloves could be improved and thus result in agricultural workers' acceptance and adoption of hand protection.

## Objectives

1. To collect a series of 19 specific hand measurements important in the design of protective gloves, from a large sample of agricultural workers who use pesticides.

2. To determine if the size range of commercially available chemical protective gloves will provide a functional fit for a representative sample of the user-population based on hand measurements.

3. To determine differences in dynamic fit among four types of gloves differing in polymer type, material thickness, and manufacturer.

4. To determine if a relationship exists between the static fit and the dynamic fit (levels of performance) of various glove types.

5. To determine agricultural workers' preferences regarding functional fit among protective gloves differing in polymer type, material thickness and manufacturer.

6. To determine whether the amount of ease found in various gloves differing in polymer type and material thickness is related to functional fit and comfort.

7. To recommend the amount of ease needed in key glove dimensions to accomodate hand size variation among agricultural workers and yet provide a good fit to individual workers.

## Null Hypotheses

The following hypotheses will be tested to meet objectives three, four, five and six:

1. There will be no significant relationship between *functional fit* (overall goodness of fit ) of the gloves and participants':

   (a) hand circumference and

   (b) length of middle finger (digit 3).

2. There will be no significant difference in *functional fit* (overall goodness of fit), *comfort*, *static fit* (total number of "just right" responses) and *dynamic fit* (levels of performance) among the four glove types.

3. There will be no significant relationships between the *dynamic fit* (levels of performance) of the gloves and:

   (a) *functional fit* (overall goodness of fit) and

   (b) *static fit* (total number of "just right" responses)

4. There will be no significant relationship between the amount of *ease* found in the key dimensions (circumference of the hand at the knuckles and the length of the middle finger) of each glove and:

   a) *static fit* (total number of "just right" responses),

   b) *comfort evaluation* s,

   c) *functional fit* (overall goodness of fit), and

   d) *dynamic fit.*

5. There will be no significant differences in the amount of *ease* among *static fit evaluation categories* for specific dimensions of the gloves.

## Definitions

Anthropometrics (applied anthropometry): A process which involves the application of numerical data concerning sizes, shapes and other physical characteristics of human beings in a design context (Pheasant,1986).

Anthropometric fit test: The evaluation of fit and function of garments or equipment with a sample of potential users that represent the size range of the user-population.

Clothing comfort : Absence of definite physiological and/or psychological response to a worn item of clothing in either a positive or negative direction (Dr. T. Nelson, University of Alberta, personal communication, 1989). Operationally defined as responses to item 1d of the Glove Evaluation, Appendix F .

Functional Apparel: Clothing that is designed to meet the physical, social, psychological, and aesthetic needs of potential users (Murray,1982).

Functional Fit: A combination of the body dimensions of a person in the anatomic position and the ease allowance necessary for movement to perform the required activities (VanSchoor, 1989). For this study it included both static and dynamic fit and the 'overall goodness of fit'.

Static Fit: A relationship between garment size and body size in the anatomic position, determined by the garment design. Wearer acceptance was estimated through subjective evaluation of quality of fit. Operationally defined as the number of *"too tight"*, *"too loose"*, or *"just right "* responses. This was measured by questions 1 through 4 of the Static Fit Evaluation, Appendix G. The total number of *"just right "* responses were added to describe the 'overall quality of fit' of each glove type.

Dynamic Fit: A combination of garment design and material that allows the body to perform with minimal garment interference and resistance. This is estimated through the speed and accuracy of an operator's ability to perform predetermined tasks such as in time motion studies. Dynamic fit is operationally defined as the time of completion of each of the Minnesota Rate of Manipulation Turning Test and the Craik Screw Test.

Overall Goodness of Fit: A subjective measure of the functional fit of a garment. Operationally defined as responses to question I of the Functional Fit Evaluation (Appendix I).

Ease: The provision of extra length or width in specific areas of a garment to allow freedom of movement (Watkins,1984). In this study, ease was operationally defined as the difference between the inside glove dimensions and participants' hand circumference, and both the length and circumferences of their fingers.

# II. REVIEW OF LITERATURE

## A. PESTICIDE SAFETY

Occupational exposure to pesticides such as herbicides, fungicides, and insecticides can be hazardous to workers if they are not used safely. For each pesticide that is introduced into the market, Agriculture Canada sets safety margins for users. These margins are primarily set on the basis of protecting applicators and users from health hazards. Because of the wide use of pesticides and of the technology available, many agrichemicals have levels of toxicity too high to be safe to workers without any protection (Franklin,1985). In such circumstances when the exposure to chemicals is equivalent to or exceeds a threshold of safety, appropriate recommendations for safe use need to be made. Detailed information about the type of protective clothing to wear while handling various pesticides and appropriate cleaning procedures are essential in reducing workers' potential exposure.

Important information needed to recommend appropriate safety measures to users include knowledge of the toxicity of the pesticide and the amount of pesticide to which workers can be exposed (Bonsall,1985). Determining the level of toxicity of pesticides remains the manufacturers' responsibility. The potential risk of pesticide contamination to agricultural workers, however, is left to the investigation of many researchers (Wolfe et al.,1967; Popendorf,1985). In general, workers who are occupationally exposed to pesticides can be harmed if pesticides are inhaled, ingested, or absorbed through the skin. In agriculture, dermal exposure has been found to be the most common source of potential worker exposure (Moraski & Nielsen,1985; Maibach, Feldman, Milby & Seurat, 1971).

In the past, much attention has been given to the estimation of agricultural workers' potential total exposure. Research findings from studies that have estimated the percent exposure to individual parts of the body, suggest that hands alone account for 20% to 97% of the total exposure (Bonsall,1985; Davis et al.,1983). Furthermore, differences in the degree of absorption exist between the palm and the outer surface of the hand. The inner surface of the hand can absorb up to 2% of the pesticides with which it comes into contact while the outer surface of the hand can absorb up to 21% (Watkins,1984).

Estimated percentages of potential hand exposure have been found to differ significantly in various studies. The wide range of differences among estimates of potential hand exposure can be partly explained by the method of assessment. There are currently three methods being used to estimate potential hand exposure to pesticides: wrist patches, cotton gloves and hand washes or swabbing (Davis,1980).

Differences can also be explained by the operation during which hand exposure is assessed and the type of equipment being used . There are four operations during which agricultural workers can be exposed to pesticides: 1)while mixing the pesticides, 2)while loading the pesticides into the tanks, 3)during spraying application and 4) when cleaning and disposing of the pesticide containers (Murray,1982). In studying the distribution of pesticide contamination over regions of the body, Abbott (1984) found that 99% of body surface exposure occured while mixing the pesticides and loading them into the tanks of the boom sprayers. During these two operations both the large amounts of pesticides and the toxicity of the concentrates increased worker's potential risk of exposure. Of the 99% total body surface exposure, 97% was located on workers' gloves. These percentages may vary depending on the type of farming. As a general rule, however, the wearing of chemical protective gloves during these operations can reduce a workers total dermal exposure significantly.

In this same study Abbott (1984) identified the percentage of pesticides covering the hands of workers operating different types of sprayers. When using tractor mounted booms, the hands of workers accounted for 66% to 86% of total exposure. The hands of workers using booms equipped with hydraulic nozzles were less contaminated than the hands of workers using booms equipped with spinning disc controlled droplet applicators. Only 33% of total body surface contamination was found on the hands when subjects used a knapsack fitted with adjustable single nozzles. It should be noted that when operating the knapsack sprayer, a large percentage of total body surface contamination was found on the legs. Therefore the lower percent contamination found on the hands does not imply less contamination of the hands but rather more overall surface contamination on the legs of the subjects.

## B. CHEMICAL PROTECTIVE GLOVES CURRENTLY AVAILABLE

Protective clothing is presently the only barrier that protects a worker from dermal exposure to pesticides. The adoption of suitable protective gear at appropriate times is a worker's first means of defense in reducing potential dermal exposure (Moraski & Neilsen,1985; Turnbull, Sanderson & Crome,1985). The wearing of gloves is especially important since most of the potential contamination is found on workers' hands. There is currently a wide variety of chemical protective gloves available to the agricultural population. Gloves made from various natural and synthetic polymers such as neoprene, nitrile, rubber and polyvinylchloride (PVC) can be purchased with or without a lining. These gloves come in a variety of thicknesses and they differ in chemical resistance and durability.

Gloves are produced with many different characteristics; however, there are different beliefs as to the protection that each combination provides (Maddy et al.,1985). Gloves alone cannot protect a worker. In fact they may aggravate contamination if they are not washed frequently, disposed of when they become old, or if they are not worn during all recommended phases of pesticide handling procedures (Maddy et al.,1985; Turnbull et al.,1985). Rather than protect a wearer from hand exposure, gloves that are over contaminated act as a constant source of pesticide to the skin and may increase the level of over-exposure.

In order to meet the demands of certain operations while handling pesticides, a worker must consider the toxicity of the pesticide and the operation during which the gloves will be worn. The chemical resistance of gloves depends on the type of material from which it is made. No glove can resist all chemicals and withstand all work hazards (Nelson, Jum, Carlson, Wong & Johnson, 1981). Manufacturers provide some information on the chemical resistance of gloves to various industrial chemicals. Data on the breakthrough time and permeation rate of glove materials to pesticides, however, are not readily available. Gloves are therefore chosen based on certain ingredients within the pesticide rather than the pesticide itself. This lack of data makes it difficult to recommend the appropriate gloves for agricultural workers. Further investigation into the chemical resistance of current glove materials to pesticides is needed.

Findings from surveys that investigated farmers' likes and dislikes with respect to chemical protective gloves, indicate that the gloves currently available are not functionally designed to meet the needs of agricultural workers (Rucker, Heffner & York,1988). In most cases the adoption of gloves means trading off comfort and dexterity for protection. In studying pesticide applicators' attitudes towards protective clothing, Rucker, Branson et al. (1988) found that a considerable number of farmers choose to wear leather and canvas gloves over chemical protective gloves. Problems associated with chemical protective gloves are loss of dexterity, poor fit, and thermal discomfort (Rucker, Heffner & York,1988; Perkins,1988).

While wearing gloves, agricultural workers experience two types of dexterity problems: the loss of sensitivity in the fingers and the buckling of glove materials in the palm of the hand (Rucker, Heffner & York, 1988). Gloves interfere with a worker's ability to manipulate small objects such as nozzles, and to open pesticide containers. Adding to problems of dexterity was the limited size range of gloves available in local stores. Growers complained about their unsuccessful search for gloves that offered an acceptable fit. Gloves that did not fit properly were said to affect both dexterity and thermal comfort. The excess bulk found in loosely fit gloves complicates manipulation. Tight fitting gloves on the other hand decrease a worker's thermal comfort.

## C. DESIGN CRITERIA

The effectiveness of protective gloves in reducing a worker's potential dermal exposure depends greatly on the glove material's ability to resist chemicals. This design criterion alone, however, does not ensure workers' acceptance and adoption of protective gloves. Comfort and ease of use are two other important design criteria that need to be incorporated in the development of successful chemical protective gloves. Ideally protective gloves should provide protection as well as permit dexterity and transmission of a wide range of pressures for tactile sensation (Roebuck et al., 1975). If protective gloves are uncomfortable or if they complicate the completion of simple tasks, they will not be worn by potential users.

### Theories of comfort

The main objective of research into chemical protective clothing for agricultural workers is to help designers and manufacturers provide agricultural workers with the appropriate protective items they need to handle pesticides safely. Research focused on the evaluation of protective clothing and wearers' preferences has found comfort to be one of the most important attributes of chemical protective clothing ( Perkins,1988; DeJonge, Vredegood & Henry, 1983-84; Carlson,1982; Murray,1982).

Scientists face conceptual difficulties defining and analyzing comfort. Some find it appropriate to describe comfort as an absence of discomfort or absence of unpleasantness (Slater,1985; Pontrelli,1977; Renbourn,1971). Research into consumers' attitudes toward comfort, hypothesized that comfort is a response, not a cause. For example, comfort has been regarded as a subjective evaluation of satisfaction or pleasantness attributed to a stimulus located outside the human body (Pontrelli,1977; Renbourn,1971). This does not necessarily imply an actual conscious feeling of pleasure but rather a neutral state of contentment with one's environment and internal state. Slater (1986) has defined human comfort as harmony between physiological, psychological, and physical responses that can be attributed to the environment.

Clothing, fabrics, yarns or fibers do not have inherent comfort properties. There are, however, certain clothing and textile characteristics that may influence a wearer's response to the feeling of comfort (Pontrelli, 1977). The physical behavior of materials, the fit of a garment and its thermal conductivity are clothing properties which can affect physiological awareness of comfort or discomfort. Color, style, and suitability of a garment for an occasion are characteristics that may affect a wearer's psychological sensation of comfort (Smith,1986).

Protective clothing which has been referred to as a worker's 'portable environment' can enhance or reduce a wearer's state of contentment (Watkins,1984). Garment properties that may affect both the psychological and physiological sensations of comfort were considered in the evaluation of chemical protective clothing used by agricultural workers (Crown, Perkins & Tremblay, 1988; Perkins,1988; Murray,1982). In the acceptance of protective clothing, properties that affect psychological sensations of comfort were found to be of lesser importance than those that affect physiological sensations (Staiff, Davis & Stevens,1982; Murray,1982). The most important attributes that determine a wearer's comfort are the functional properties of protective clothing (Slater,1985; Watkins,1984; Carlson,1982; Murray,1982).

**Measurements of Comfort and Related Factors**

Since comfort is a purely subjective response, care must be taken in the way it is measured. "Although it is impossible to measure comfort as a total state of mind or body, there are many ways in which factors relating directly or indirectly to comfort can be assessed" (Slater, 1986, p.170). Generally, psychological factors affecting comfort responses can only be measured subjectively; physical factors are measured objectively through laboratory tests; and physiological factors can be measured both objectively and subjectively (Slater, 1985).

Researchers have used various laboratory methods to measure factors such as material thickness, flexibility, friction and thermal insulation. When a physical property of a material is known to influence the sensation of comfort, laboratory tests may be used to measure the property. A glove system, however, consists of a variety of these physical factors. The relationships that exist among many of these factors is difficult if not impossible to define (Bradley,1969b). All of the factors act simultaneously within a glove system. Therefore, obtaining quantitative measures of the effect of each physical factor independently are not attempted. For the purpose of this study, the polymer type, material thickness, and surface texture of specific glove systems were investigated for their joint effect on comfort.

Fit has been described as a factor affecting the physiological sensations of comfort. Physiological comfort depends on factors such as body temperature, tactile sensations, neural responses, and mechanical efficiency. Each of these factors can enhance or impede an individual's level of comfort. Unsatisfactory levels of any one or all of these factors will affect performance efficiency. Depending on whether dynamic or static fit is being measured, both objective and subjective techniques can be used .

A purely objective method of measuring physiological comfort of protective clothing is to measure the dynamic fit of the clothing system. By definition, dynamic fit refers to whether a garment allows the body to perform usual tasks without garment interference and resistance. Conditions for optimum comfort guarantee the best conditions for performance and well being (Nelson, Nilsson & Hopkins,1987). The speed and accuracy of an operator's responses while wearing protective gear is therefore critical in the success of the garment (O'borne, 1982). Two methods commonly used to evaluate the effects of clothing on mobility are simple motor tests and time motion studies.

Simple motor tests are used to measure the movement allowed by particular clothing items. In these studies participants may be asked to reach the farthest point on a grid or bend to touch specific points on the floor while wearing various clothing items (Watkins,1984). For example, to measure the restriction in the crotch and leg area of pants, subjects were asked to take five steps backward in three different outfits (Saul & Jaffe in Watkins,1984). The performance for each outfit was based on the total length of five strides. Another approach used to evaluate the effects of clothing on performance is to compare a subject's performance scores in the presence and absence of the test garment.

As the name implies, time motion studies are concerned with how quickly a subject can complete a certain task. Both simulated working environments and standardized test batteries can be used to measure performance. By using standardized test batteries, the time of completion and accuracy observed while performing predetermined tasks can be used as objective measures of dynamic fit. Most of the glove studies concerned with the effects of gloves on fine manipulation have used dexterity batteries such as the Minnesota Rate of Manipulation Test, the Craik Screw Test and the Purdue Pegboard (Groth & Lyman,1958; Lyman,1957; Sheridan,1954).

The adoption of simulated environments is particularly important when the investigator is concerned with the design of the working place (Roebuck et al.,1975). Studies that have looked at the effects of gloves on control manipulation used laboratory control panels designed to simulate real aircraft conditions (Bradley, 1969a,1969b; Bradley & Stump,1956). One of the objectives in these studies was to recommend the size, shape and materials of controls that could improve operators' ability to perform while wearing gloves; therefore simulated conditions were important.

Static fit which is determined by the design of the garment, is the relationship between garment size and body size. The difference between the two sizes is referred to as ease and can be represented numerically. Although ease can be measured objectively, individual preferences for comfortable amounts of ease can only be determined subjectively. While some participants may prefer tight fitting gloves, others may respond to a tight fit as being uncomfortable. The need for subjective measures are therefore required for a complete evaluation of the functional fit of protective gloves.

The subjective evaluation of specific clothing systems is fairly simple to conduct. The assessment usually consists of asking subjects to indicate if their levels of comfort diminish or increase as a result of the changes that are introduced (Slater,1985). A common technique used to measure participants' subjective assessments of comfort is psychological scaling. These scales depend on the judgment scales people collect from experience and share with others throughout their lives (Hollies, 1977). When speaking of clothing, comfort sensations felt while evaluating the fit of a garment will depend on participants' past experiences; any deviation or change from what is usually considered comfortable, will be considered uncomfortable.

Semantic differential scales are often used during subjective evaluations of comfort. The scales enable the researcher to measure both the direction and the intensity of a respondent's feeling towards a given concept. For example, when asked to rate the fit of the gloves on a seven point scale:

good fit ____:____:____:____:____:____:____ poor fit

the respondent indicates whether the fit is good or poor (direction), and to what extent the fit is good (intensity). Assuming each interval is equal, the responses can be quantified as +3, +2, +1, 0, -1, -2, -3, or from 1 to 7. All scales used in the static fit evaluation can then be averaged across respondents to develop semantic differential profiles. An overall evaluation of individual glove types can be achieved while taking into consideration the values given to individual items.

The semantic differential scales also allow the researcher to compare the goodness of fit of a number of glove types. Although all the gloves may be rated as having a 'poor fit', the fit of glove type A (-1) may be better than glove type D (-3). If the data are coded from 1 to 7, the same interpretation applies. With 1 corresponding to poor fit and 7 to good fit, the fit of glove type A (3) may be better than glove type D (1). In this study, one of the objectives is to evaluate the quality of fit of various glove types and then compare each of the gloves. The semantic differential scales were therefore used in the development of the instrument.

## Hand Dexterity

Ease of mobility is an essential criterion to consider in the development of functional protective clothing. Like all protective apparel, gloves act as an interface between the worker and the task that needs to be completed. If the gloves restrain usual hand movements a worker must constantly work against the gloves and therefore wastes energy that could be used to complete a task (Watkins,1984). The muscular exertion or fatigue resulting from straining may cause discomfort and consequently reduce performance effectiveness (O'borne,1982). The success of protective gloves depends on the extent to which a worker's rate of performance and accuracy is affected. The more gloves interfere with performance the less comfortable they become.

The inclusion of a glove material between an external object and the hand of a worker has two major effects. Information to the cutaneous senses are distorted and the forces applied to external objects act through materials which have different properties than those of the bare hand (Lyman and Groth,1958; Lyman,1957; Sheridan,1954). These problems have been found to be most detrimental to the fine manipulation of the hand. Walk (in VanCott1964) investigated the effect of gloves on hand manipulation using the Perdue Pegboard to measure tactile performance. The performance of the gloved hand was found to be 65% that of the bare hand.

Further evaluations of the effect of gloves on hand manipulation suggest that the major source of impairment to fine manipulation is localized at the end of the fingers (Sheridan,1954). Eight glove configurations including an intact glove assembly, a glove with the ends of the fingers cut off, and ends of gloves by themselves, were compared. Performance of each configuration was recorded as the time required to complete the Minnesota Rate of Manipulation Turning test, the Craik Screw Test, and the Plug Insertion Test. The average scores when the ends of the fingers were covered were consistently greater than the scores of uncovered fingers. The performance scores of gloves with the ends of the fingers cut off were only slightly greater than the scores of the bare hand condition.

There is a general agreement that even the thinnest surgeon's glove leads to a measurable performance decrement when fine manipulation is involved in an operation (Groth & Lyman, 1958). However, some studies found that for certain tasks gloves may have no measurable effect on performance. In an experiment where subjects were asked to operate various types of knobs, gloves did not interfere with reach times and turning times(Bradley & Stump,1956). From these findings it was suggested that for gross manipulations requiring information from the muscles and the joints, gloves may be expected to have little detrimental effect on the hand's ability to perform. The major effect of glove occurs when a task requires fine sensation of the skin. When gloves are designed for a specific purpose the task to be completed must be carefully analyzed for the requirements of human hands (Watkins,1984; Lyman,1957)

Decrement in performance results from the interference of glove materials with cutaneous cues (Groth & Lyman, 1958;Sheridan, 1954). Physical properties of glove materials such as thickness, bulk, flexibility and friction limit the precision of information available to skin senses. Studies of the effect of glove materials on manipulation and operation time recommend different combinations of properties for different types of tasks. In general stiff materials impair dexterity more than flexible materials, especially when the surface friction of the material is low (Bradley,1969a, 1969b; Groth & Lyman,1958; Sheridan,1954). One exception to this rule is that for fine manipulative tasks such as turning screws, a stiffer material with slightly less surface friction is preferred.

## Fit of Protective Gloves

"Poor anthropometric fit and fatigue have been emphasized as contributing factors which help reduce performance effectiveness "(O'borne,1982). Ideally, protective gloves should be designed to accomodate the hand dimensions of the user-population. Fit is an important factor in determining the comfort of protective apparel. Failure to provide sufficient ease and flexibility can be critical to the worker and jeopardize performance and safety (Hertzberg,1972). During various surveys, agricultural workers have complained about the fit of chemical protective gloves currently available (Perkins,1988; Rucker, Heffner & York,1988; Hussain,1983). Although a gloved hand cannot perform fine tasks as well as a bare hand, a glove designer's goal should be to discover methods of achieving optimum comfort and hand manipulation. In addition to protecting workers from pesticides, gloves should allow a worker to undertake and complete usual tasks without considerable decrement in performance.

A glove which is too tight tends to squeeze the hand and fingers, and restrict proper blood flow. This can prevent or reduce the fingers' ability to sense forces transmitted from external objects (Sheridan,1954). Too tight a fit may also restrain the hand's ability to manipulate. A glove which is too loose may cause different problems to the wearer. Fingers may slip inside the glove causing changes in the direction of forces being exerted. Excess material in the palm of the hand or at the joints of the fingers may 'buckle' upon bending the fingers or clenching the fist. Consequently, the pressure applied at localized areas may cause feelings of discomfort (Denton,1971; Watkins,1984). Bulk at the ends of the fingers or in the width of the glove may be hazardous to the wearer by getting caught in machinery.

In addition to the problems incurred by the physical properties of the materials, the fit of protective gloves has been shown to be a major determinant in a worker's ability to complete manipulative tasks effectively. Bradley (1969a, 1969b) conducted two experiments that looked at the effect of gloves on control manipulation and operation time. A variety of 21 gloves differing in surface friction, thickness, flexibility and snugness were included in the study. The findings from both studies strongly indicate that for control manipulation, loose fitting gloves are inferior to tighter fitting gloves. Snugness was the only characteristic which correlated significantly with operation time of both push button and adjustable controls. Adjustable controls were operated more quickly with a tighter more supple glove. A tight stiff glove with high friction allowed subjects to operate the push button control more efficiently.

The loss of hand dexterity while wearing gloves is a common complaint addressed by agricultural workers. Cleaning and adjusting nozzles have been identified as major difficulties encountered in the fields (Rucker, Heffner & York,1988). To effectively complete fine manipulative tasks Bradley (1969b) recommends the use of tightly fitted gloves. The tight fit will prevent fingers from moving inside the glove when in contact with the nozzle. There will also be minimum interference between the pressures exerted by the finger and the forces applied to objects. During the mixing and loading of pesticides more protection is required and fine dexterity is less critical. Under these conditions a thicker more protective glove can therefore be used efficiently.

## Anthropometric Data

Prior to the development of protective apparel, a designer must have some knowledge of the body dimensions of the potential user population. A glove designer must particularly have some data on the 'physical size' of workers' hands. The literature review found that various hand measurements are needed for different design problems. A total of 56 hand dimensions measured by various researchers are included in Garrett's (1971) summary of hand anthropometry for equipment design. The study identifies key dimensions to consider when designing gloves, control knobs and working environments.

The nature of the design problem decides whether a designer must collect static or dynamic anthropometric data. Dynamic measurements sometimes referred to as functional anthropometrics consist of the measurements of the hand and its immediate surroundings. These measurements are used to determine the size of controls, knobs and handles, or define a reach capability for a hand in specific positions (Garrett, 1971). The main purpose of collecting dynamic measurements is to describe the environment in which the working hand must operate.

Static anthropometry also referred to as structural anthropometry includes measurements taken to describe the physical size of the hand. Key dimensions are measured between specified anatomical landmarks on the straightened hand (Pheasant, 1986; Hertzberg, 1972). All dimensions include circumferences and linear distances along the surface of the hand. The static measurements which describe the physical characteristics of the hand are particularly important to the designer who must develop functional sizing systems for the design of protective gloves.

Consideration of both static and dynamic anthropometry are required in the successful development of a 'man-machine' system (Roebuck et al., 1975). While dynamic anthropometry is concerned with the size and shape of the work space, static anthropometry is primarily concerned with the relationship between a worker's body dimensions and the internal shape of clothing. The quality of fit of protective gloves and workers' functional preformance while wearing the gloves were the main objectives of this study. The hand dimensions collected during the anthropometric survey were, therefore, static in nature in order to investigate relationships between farmers' hand sizes and the design of gloves.

Sizing systems are usually set to accommodate people with body measurements from the 5th to the 95th percentile. Accomodating only 90% of the population would mean that 10% of the population would have to accomodate themselves to available sizes. When clothing is worn for safety reasons, individuals who would not find acceptable sizes would be at risk . It has been suggested that to be successful, protective clothing should provide adequate fit for at least 98% of the potential user-population (Jürgens,1984). In meeting such standards, the remaining 2 % of the population could presumably accomodate themselves to available sizes. Such standards, however, may not be feasible for certain clothing items. The designer should therefore accommodate 90% of the population as a minimum and strive to meet the needs of 98% or more. Anthropometric information becomes immensely valuable in the development of these sizing systems.

The development of protective clothing requires the knowledge of potential users' body dimensions if the clothing design is to enhance the efficiency, the safety and the comfort of workers (Roebuck et al.,1975). Anthropometric data for male and female working populations are sparse and unsatisfactory. Information which is available is derived from large anthropometric surveys of military personnel and civilian populations, and is usually very general in nature. Earlier statements have indicated that protective clothing should be designed to accommodate the population that will be wearing it. When this information is not available for specific user-populations indepedent anthropometric surveys sould be conducted. Anthropometric surveys, however, are often too time consuming and expensive to conduct if they are to be done satisfactorily (Pheasant,1986).

Information on hand measurements in general is limited. The largest study located and commonly referenced in anthropometric literature is the survey of 4000 flying personnel conducted by Hertzberg, Daniels & Churchill (1954 ). The purpose of the study was to determine how 'man's skin fits him'. One hundred and thirty dimensions were measured on every subject. The pool of data collected during this study includes ten measurements related to the design of pressure gloves. In another study hand measurements were collected from military personnel to derive an appropriate sizing system for pressure gloves (Barter & Alexander, in Roebuck, 1975).

These two studies offered large pools of hand measurements but could not be used in the present investigation for two reasons. Significant differences in body dimensions among groups with different nationalities, occupations, ages, and sex are well documented (Pheasant,1986; Roebuck et al.,1975; Hertzberg,1972). The hand dimensions of military personnel, therefore would not reflect those of agricultural workers. For design purposes body measurements should also be as current as possible. Every decade, the size of the human body increases by 10% (Roebuck et al., 1975). Direct use of earlier data would not be indicative of current sizes. There are more recent tables of body measurements which include hand length and width (Pheasant,1986). The number of hand dimensions included in these tables, and the populations for which they are documented are limited.

## D. FUNCTIONAL DESIGN OF PROTECTIVE APPAREL

### Development of prototypes

Incorporating mobility into a protective garment is a complex task which requires a certain degree of skill and engineering (Watkins,1984; Orlando,1979). For this reason, the design of functional protective clothing differs from the design of every day clothing. The main objective is to meet the specific needs of a given population. The *Functional Design Process* described by Orlando (1979) illustrates the complexity involved in ensuring the successful development of protective apparel. This process takes the designer from the general request for a protective item to the evaluation of the final design.

The two-part design effort consists of "carrying out the search for a suitable design and a strategy control which controls and evaluates the pattern of the search" (Orlando,1979, p. 128). In the early stages of development, a designer must first familiarize him/herself with the potential user population. This includes knowledge of the body dimensions of the potential users, descriptions of specific tasks that need to be completed while wearing protective gear and descriptions of environmental factors that may affect the performance of the garment. Critical factors are then isolated and the design problem is defined.

Following the initial search, specific activity assessments are conducted to identify the factors which are more closely related to the specific design problems. Factors such as movement and body temperature are usually assessed at this stage. The number of factors and the degree to which they are assessed varies with the problem being studied. Once the critical factors have been carefully observed, design specifications are formulated. In the final stage the designer sets priorities among the specifications and completes the design criteria. Prototypes are developed and evaluated by potential users.

Ideally, fit and performance tests should be conducted throughout the design process of all protective equipment (McConville,1986). Unfortunately, these tests can be time consuming and expensive to conduct and therefore they are often omitted from the design process. Fit and performance tests are usually called for after problems have developed in manufactured items (McConville,1986). During preliminary fit tests with potential users, designers can effectively evaluate sizing and design problems. Problem areas which may interfere with a worker's performance can also be identified. The present investigation is concerned primarily with this part of the *Functional Design Process*. By observing factors that affect hand manipulation through field observations, it may be possible identify characteristics that may be considered for constructive redesigning of gloves.

To develop specialized clothing that will meet stringent requirements such as protection and comfort, both practical and statistical considerations are required. The *Engineering Anthropometry Clothing Design Model* complements Orlando's (1979) *Functional Design Process* in that statistical-anthropometric data are used as a basis for developing the design criteria of protective clothing (Roebuck et al.,1975; see figure 1). This model is an anthropometric approach to the design and evaluation of protective clothing. It focuses primarily on the development of statistical sizing systems based on the user-population's body dimensions.

The model provides a designer with a series of steps to be accomplished throughout the development cycle. The designer must consider functional properties of garments, the work space environment and the cost of development of protective items to determine the most critical dimensions which should be used as a basis for statistical sizing systems. The natural anthropometric variability of the statistical sizing studies are also considered during the development. This model illustrates how anthropometric data are incorporated into important stages of the design process.

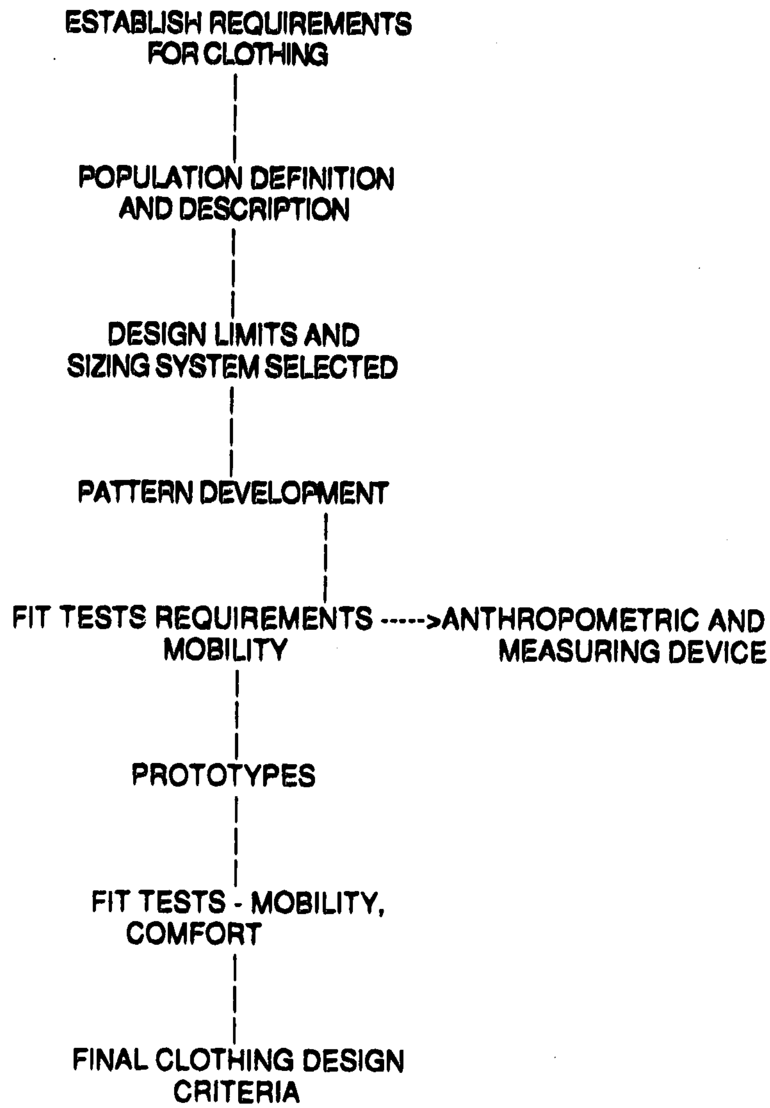


Figure 1. Engineering Anthropometric Clothing Design Model (Adapted from Roebuck et al.,1975)

**Evaluation of the performance of protective apparel**

"The direction of progress is the direction of adapting equipment to the capabilities of men rather than adapting men to the capabilities of equipment" (Lyman,1957, p.92). Sharing this goal, researchers in the field of ergonomics, human factors and human engineering have investigated ways to improve human performance by designing equipment and machinery that fit the individual and the environment. The criteria used in the evaluation of a man-machine system are based on the welfare of the user with consideration of safety, ease of use, and comfort. Poor acceptance of a protective item and decrements in performance while using the item, reflect problems in the product design (VanCott,1972).

Garments and equipment designed for special purposes must fit a selected population and function under specified conditions. "For general use, any design which imposes limitations by using unsuitable dimensions unnecessarily complicates its use " (Croney,1980 p.85). When a product is not performing well a researcher must reevaluate the design process and determine the factors that contribute to the poor acceptance of the item. Hertzberg (1972) described a number of procedures which should be followed when evaluating "equipment" such as protective apparel.

As in the design process, the investigator must have some knowledge of the body dimensions of the user-population. Initially, the investigator must obtain percentile data on the range of sizes of the potential user-population. Reference to current anthropometric data banks may provide the necessary body dimensions needed for general descriptions of certain populations (McConville,1986). When existing anthropometric data banks do not provide sufficient information for specific body dimensions or for a particular subpopulation such as agricultural workers, the investigator may be forced to conduct his or her own anthropometric survey.

A small sample can then be selected for the evaluation study, and measured to as age, occupation and sex must also be considered to ensure the selection of a representative sample (Pheasant, 1986; Roebuck et al.,1975; Hertzberg,1972). The evaluation protocol consists of dressing the subjects in the protective equipment to be tested and any other equipment which normally may interfere with the performance of the test garment. At this stage the static fit of the best fitting size is evaluated (Gordon, 1986).

In the final step, subjects are asked to complete various predetermined tasks or body movements to simulate the dynamic fit of the garment. The specific tests chosen for this evaluation depend on the objectives of the study and the nature of the work operations being analyzed. When environmental conditions are included in the investigation, subjects may be required to wear garments for as many hours as standard operations require. During these operations any shortcomings in the design must be recorded. Important factors to note are degradation in comfort, efficiency, and safety in relation to the percentile of the user-population (Hertzberg,1972). Both quantitative evaluations of fit and user feedback are important in determining the effectiveness of the product being tested (Orlando,1979).

# III. METHODS AND PROCEDURES

The purpose of this study was to evaluate the functional fit and comfort of commercially available protective gloves recommended to agricultural workers who use pesticides, and to investigate the joint effect of polymer type and thickness of glove materials on fit characteristics. An anthropometric approach to the analysis was chosen as an appropriate means of investigating possible sizing and design problems related to currently available chemical protective gloves. In order to evaluate the functional fit of gloves, some information on the hand dimensions of the potential user-population was essential for the selection of the small representative sample. From the review of literature the author found no available data on the hand dimensions of agricultural workers. Therefore this study was divided into two parts.

Part A of the study consisted of the collection of hand measurements from Alberta agricultural workers. These data were then referred to in the selection of a smaller sample, representative of the hand dimensions and age distribution of Alberta agricultural workers. The evaluation of the functional fit and comfort of specific chemical protective gloves which are currently available was the focus of the second part of the study.

## Part A: Anthropometric Survey

The main objective of the anthropometric survey was to collect hand measurements important in the design of protective gloves, from a large sample of agricultural workers. The nineteen specific hand dimensions measured in this survey

(Appendix A) were based on other anthropometric surveys concerned with the design of gloves (Courtney,1984; Davies, Abada, Benson, Courtney & Minto,1980; Garrett,1971). All participants were asked to sign a consent form before having their hand measured. A data sheet with all of the hand measurements and general information about participants' personal background such as age, birthplace, and ethnic background were completed for each participant (Appendix B). The survey took place at various rural functions throughout central Alberta. Eligible participants included any adult male agricultural worker who used or had used pesticides and who was currently farming.

According to Roebuck et al. (1975) "a sample must be selected large enough to assure the accuracy and representativeness of the results while being small enough for the survey to stay within budget and schedule constraints" (p.154). The following formula (Roebuck et al.,1975) was used to approximate the required sample size for specific hand dimensions:

$$N = \left(\frac{K\ S}{d}\right)^2$$

where N = sample size required;
S = estimated standard deviation of the data;
d = the desired accuracy of the measurement (± d units)
K = constant for the percentile required (eg. 5.67 for the 2nd and 98th percentile).

The estimated standard deviation (S) used to determine the approximate sample size of the present study was chosen based on the standard deviations found in previous studies (Hertzberg 1954). Of the 19 specific hand dimensions to be measured, the standard deviation of hand length (8.6 mm) was found to be the greatest and therefore was used to calculate the approximate sample size required for this anthropometric survey.

The level of accuracy required in anthropometric surveys varies according to the purpose of the data collection. For most practical design problems "accuracy is desirable but neither realistic nor entirely necessary" (Pheasant,1986; p.67). In terms of accuracy, a designer cannot have complete confidence in tables of anthropometric data. Such data must be regarded as a set of 'provisional estimates'. In general most anthropometric measurements are reported to the nearest centimeter (Roebuck et al.,1975). Pheasant (1986) adds that a level of accuracy greater than ± 5mm is virtually impossible in most anthropometric measures. The human body has very few sharp edges; because of the rounded contours of the body and of the deformation of muscles and skin, it becomes difficult to identify landmarks and control posture. Higher levels of accuracy may be required for the design of specialized protective items such as face masks. For the design of gloves, the author believed a level of accuracy greater than 5mm was required, therefore the desired accuracy of measurement (d) for this study was 2.5mm.

To determine the number of subjects required to describe the hand dimensions of a given percentile a constant value (K) is incorporated into the formula. In Chapter 2, it was mentionned that for protective apparel a designer's goal should be to accommodate at least 95% of the potential user-population. For the 2nd and 98th percentiles, the value K is 5.67 (Roebuck et al.,1975). Consequently, to know the hand measurements of 96% of the user-population, with an accuracy of 2.5 mm, a sample of at least 380 subjects is needed, calculated as follows:

$$N = \left[\frac{(5.67)\ (8.6)}{(2.5)}\right]^2 = 380$$

Anthropometric instruments used during the survey included digital vernier calipers, a measuring tape and a transparent ruler with millimeter markings, a finger template, and a graduated cone. The calipers were used to measure linear distances such as finger lengths, hand depth, and hand breadth at thumb. Hand length was measured with the ruler. The circumference of the hand at the metacarpale and the circumference of the fist were measured with a measuring tape. The finger template with holes having a 1mm increment in diameter was used to measure the diameter of participants' fingers. Grip diameter was measured using the graduated cone.

Three individuals measured and recorded hand measurements during this anthropometric survey. Inconsistencies in the measurement of body dimensions may result when more than one individual is doing the measuring or from one measurement to the next. To obtain consistent results, accuracy within ± 1mm on either side of the mean is required for small measurements such as hand breadth (Roebuck et al.,1975). For larger dimensions, accuracy to the nearest ± 5mm is sufficient. To ensure repeatability of measurements, reliability tests were conducted to compare the accuracy of the three researchers. The level of accuracy suggested by Roebuck et al. (1975) was found for most of the hand measurements (Appendix C).

All dimensions measured with the ruler and tape are reported to the nearest millimeter. Dimensions measured with the vernier callipers are recorded to the nearest 0.1mm. For each hand dimension the mean, standard deviation, coefficient of variation, and selected percentiles were calculated.

## Part B: Evaluation of Functional Fit and Comfort

The procedures involved in an anthropometric evaluation of protective apparel have been described in chapter 2. Figure 2 illustrates the steps that relate to this study. Based on the anthropometric survey (Part A), a group of participants representative of the hand dimensions and age distribution of Alberta agricultural workers were selected for the fit evaluation. The 19 specific hand measurements were recorded for each subject. The key dimensions used in the development of chemical protective gloves are hand circumference at the metacarpale and hand length. The author believed, however, that the length of the middle finger was more important than hand length in the evaluation of fit. Therefore, participants for the fit evaluation were selected to represent the hand circumference and the length of the middle finger (digit 3) of the user-population, as indicated by the anthropometric survey.

Definition and description of
the user-population
|
Selection of
a representative sample
|
Static Fit Evaluation
|
Dynamic Fit Evaluation
|
Criteria for
constructive redesigning

Figure 2. Anthropometric Evaluation of Protective Apparel

Each participant was asked to evaluate and compare the functional fit of four types of gloves. The gloves chosen for this study represent various combinations of polymer type, material thickness and manufacturer currently available on the market (Table 1). Nitrile gloves are recommended to agricultural workers because of their resistance to oils, and their excellent tensile and tearing strengths. The selection of nitrile thus seemed appropriate for this study. A tripolymer glove made from nitrile, neoprene and latex was also included in the evaluation to compare the effect of polymer types on fit characteristics. In addition to the four glove types, a bare hand condition was used during the evaluation to provide a standard performance score.

Table 1

Glove Types

| GLOVE TYPE | MANUFACTURER | POLYMER | THICKNESS | SURFACE | SIZE/LENGTH |
|---|---|---|---|---|---|
| [a] A | Pioneer | Nitrile | 15 mil | textured | 9-11/13" |
| B | Pioneer | Nitrile | 22 mil | textured | 9-11/13" |
| C | Pioneer | Tripolymer | 19 mil | textured | 8-11/12" |
| D | Surety | Nitrile | 15 mil | textured | 9-11/14" |

[a] [ indicates the various comparisons to measure the effect of polymer type, thickness, and manufacturer.

The gloves chosen for this study are available in sizes 7 to 11. During preliminary studies and the anthropometric survey, participants were asked to indicate the glove size they would prefer. Size 9 was the smallest glove size selected, therefore only sizes 9 to 11 in the nitrile gloves were included in the research design. Size 8 was included only for the tripolymer glove due to the flexibility of the polymer. To obtain unbiased findings, it is estimated a minimum of 8 subjects are needed for each treatment. Four glove types were evaluated, therefore a minimum of 32 subjects was needed for the evaluation of fit and comfort. A total of 38 subjects participated in the evaluation.

## Selection of Participants

Various personnel members from Alberta Agriculture were contacted and asked to submit names of potential candidates interested in participating in the evaluation of the functional fit and comfort of chemical protective gloves. Potential candidates were informed of the purpose of the study, the test protocol and the amount of time required to complete the evaluation. In order to participate, candidates were expected to be male farmers at least 20 years of age with some experience in handling pesticides. Volunteers were expected to be grain growers or involved in mixed farming where some grain was grown. Individuals with arthritic or other muscular pains in their hands were not allowed to participate. Potential candidates were told that they would be given a pair of gloves in appreciation for their participation.

The District Agriculturalists and Home Economists involved in recruiting volunteers were most cooperative. The names of 42 potential candidates were submitted within two weeks of the initial contact. Upon receipt of a list of names, the researcher contacted the volunteers by telephone and scheduled appointments at their convenience. Three of the volunteers were unable to participate on the specific days of testing, and one candidate did not attend after making an appointment. A total of 38 agricultural workers participated in the fit evaluation.

A table of percentile values prepared from the Anthropometric Survey (Part A) was used to monitor the hand dimensions of participants, in order to ensure that the sample respresented a wide range of hand sizes relevant to the user population. The key hand dimensions of the initial 38 volunteers were judged to adequately represent the size range of the agricultural workers. The bivariate table in Figure 3, shows how the individuals from the functional fit evaluation are distributed over the entire size range of the agricultural population's hand circumference and length of middle finger. The hand circumference of participants ranged from the 3rd to the 95 th percentile and the length of the middle finger ranged from the 8 th to the 99 th percentile. A fairly regular distribution of hand sizes existed for both key dimensions.

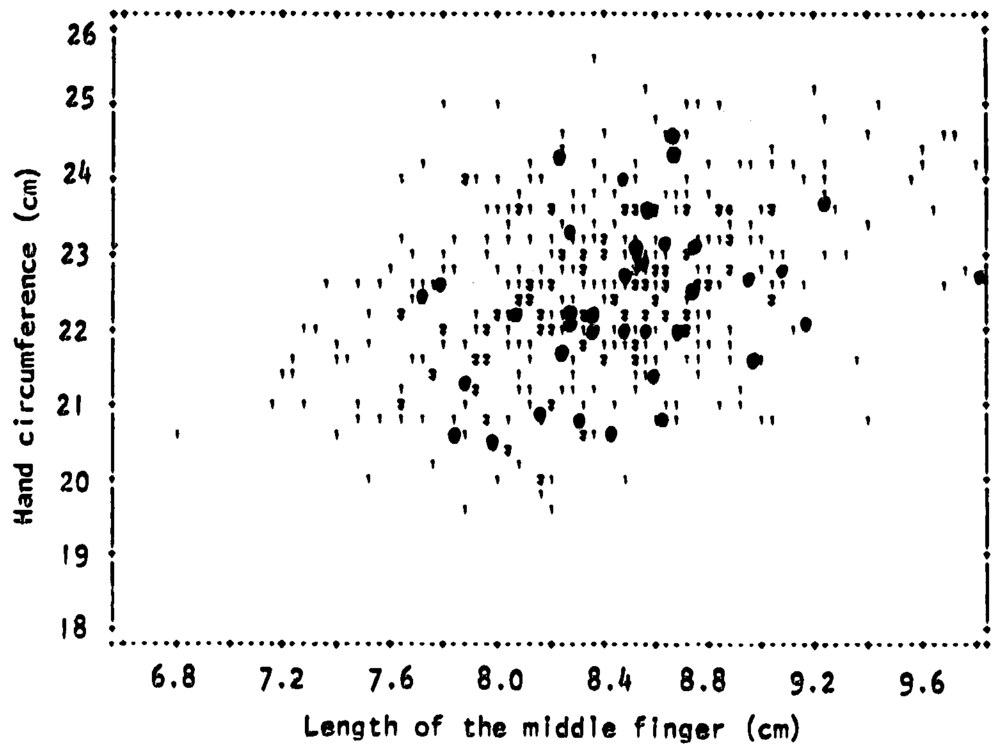


Figure 3. Bivariate Frequency Distribution of Participants in the Fit Evaluation (•), Compared to Distribution of Agricultural Population.

### Structure of the Study

Testing laboratories were set up in Alberta Agriculture offices located within reasonable travelling distances from the volunteers' farms. Seven days of testing in two towns outside of Edmonton were needed to schedule all of the volunteers. Because of the interest in improving the fit of chemical protective gloves and the timing of the study, participants were most cooperative in taking one hour of their time to participate in the evaluation. Prior to the evaluation, participants were briefed concerning the purpose of the study and the test protocol, and then asked to sign a consent form before any of the testing took place ( Appendix D). The hands of participants were then measured and personal background information recorded, such as in the anthropometric survey.

**Order of Presentation of Gloves**

To control for possible order effects and learning effects, the order of presentation of gloves was predetermined. Seven possible combinations were established to ensure that each glove type was presented to a participant prior to each of the other three glove types and the bare hand condition at least once (Table 2). Each glove type was also presented in all possible orders. For example glove A was followed by gloves B, C, D and the bare hand condition at least once. Glove A was also presented to participants either in first, second, third, fourth, or fifth place. The seven possible combinations were randomly assigned to participants.

Table 2

Order of Presentation of Gloves

| Order Code | First | Second | Third | Fourth | Fifth |
|---|---|---|---|---|---|
| 1 | Bare | Glove B | Glove C | Glove A | Glove D |
| 2 | Glove D | Bare | Glove A | Glove B | Glove C |
| 3 | Glove C | Glove B | Bare | Glove D | Glove A |
| 4 | Glove B | Glove A | Glove D | Bare | Glove C |
| 5 | Glove A | Glove C | Bare | Glove B | Glove D |
| 6 | Glove A | Bare | Glove D | Glove C | Glove B |
| 7 | Glove C | Glove D | Glove B | Glove A | Bare |

Note: Refer to Table1 for description of glove types.

## Evaluation of Static Fit

During the glove evaluation, participants were required to evaluate each of the four glove types. The first part of the evaluation consisted of the Choice Exercise (Appendix F). For each glove type, participants were asked to choose the glove size they felt offered the best fit. Participants were told that their choice of gloves should reflect what they would normally choose for mixing and loading pesticides, opening pesticide containers and adjusting or cleaning nozzles. For each pair of gloves, participants were then asked to complete the Glove Evaluation. A seven point semantic differential scale was used to measure the quality and intensity of five glove characteristics. Properties such as the weight of the glove and the stiffness of the material were used as descriptive data. The tightness and goodness of fit were used to determine whether subjects preferred a tight or loose fitting glove.

In the Static Fit Evaluation respondents were asked to describe the fit of the gloves in specific hand dimensions (Appendix G). The selection of dimensions was based on problem areas identified by 39 respondents to a preliminary survey, as well as typical key dimensions used in designing gloves. The purpose of this exercise was to determine the quality of the fit, not the intensity of that quality. Therefore, unlike the Glove Evaluation which had seven intervals, only three possible responses (too tight, too loose, just right) were used to describe the fit of each dimension. To describe how well the glove fit the participants' hands, the number of '*just right*' responses was tabulated for each glove type. This score was used to describe the quality of the static fit of each glove and then used in the testing of null hypotheses 2, 3, and 4.

## Evaluation of Dynamic Fit

To evaluate the dynamic fit of the gloves, participants were required to complete both the Minnesota Rate of Manipulation Turning Test and the Craik Screw Test while wearing each of the four glove types and once barehanded. The time of completion for each of the four treatments and the standard score were recorded (Appendix H). The criteria of performance were the times required to complete each of two dexterity tests (Minnesota Rate of Manipulation Tests Examiner's Manual,1969; Sheridan,1956). The completion time for the barehanded condition was accepted as standard (100%) performance. The completion time for each glove was compared to the bare hand. The additional time needed to complete each test was indicative of the decrement in performance due to the presence of the glove.

Any reported changes related to the evaluation of static fit were recorded following the dexterity test for individual glove types. Following all of the dexterity tests, the final part of the experiment consisted of an evaluation of the overall goodness of fit of each glove type and participants' glove preferences (Appendix I), as well as the completion of a short Background Questionnaire (Appendix J).

### Description of Dexterity Tests

The use of standardized dexterity tests have proven to be a successful method of determining the effect gloves have on an individual's rate of performance (Ervin, 1988). The selection of an appropriate test for a particular problem is the first consideration in accurately assessing the effects of gloves on the completion of specific tasks typically executed by a user-population. When adjusting and cleaning nozzles or opening pesticide containers, relatively fine manipulation of the fingers and cutaneous sensations at the tip of the fingers are required. Based on previous studies and consideration of the fine tasks carried out by agricultural workers, the Minnesota Rate of Manipulation Turning test and the Craik Screw Test were chosen for this study.

The standard Minnesota Rate of Manipulation Test was used to study the effect of the treatments on a task requiring two handed coordination with relatively gross grasping and positioning movements. The test board consists of 60 wooden cylinders, red on one side and yellow on the other. On the test board there are four rows of fifteen cylindrical holes. Each cylinder fits into one of the holes. The test was conducted with the participant standing facing the test board which was 85 cm from the floor.

To complete the test, participants were told to begin at the upper right hand corner, and, working across the top row from right to left, lift each block from its hole with the lead hand, turn it bottom side up, and replace it in the hole with the trailing hand. On each successive row, participants started with the opposite hand and worked in the opposite direction. The test was completed only when all of the blocks were properly placed in the holes (Minnesota Rate of Manipulation Tests Examiner's Manual 1969).

The Craik Screw test was used to study the effect of gloves on a task requiring relatively fine grasping and positioning movements. This test consists of a block of wood 44.5 cm by 6.3 cm by 3.2 cm with a metal strip fastened at the top. The metal strip contains 4 mm holes spaced in a line between 1.3 cm centers. Ten screws are inserted through the holes in the metal strip to corresponding nuts which are located approximately 1 cm below the strip. Each screw is 2.3 cm long and can be inserted or unscrewed by approximately four complete turns. One hole is left vacant at one end (Sheridan, 1956). The block was placed near the edge of a table, 75 cm from the floor. Participants remained seated during this test.

The test board was placed with the vacant hole near the participant's dominant hand. To complete the test, the original instructions state that the participant must unscrew the screw next to the vacant hole and screw it into this hole. When each screw is completely inserted, the participants must then unscrew the next screw and insert it into the hole from which the previous screw was taken, requiring the participant to move all of the screws in both directions. Preliminary findings from pilot tests indicated that moving all the screws in only one direction was sufficient to identify differences among glove types. Therefore, to minimize subject boredom and prevent muscle fatigue, participants were required to move all of the screws in only one direction. This test was conducted only with the dominant hand and was completed as quickly as possible.

Extraneous factors such as learning, boredom, and fatigue may interfere with the "true" measure of performance (Ervin,1988). These factors were controlled by allowing sufficient practice trials and randomizing the order of presentation of gloves to participants. Following preliminary testing, the researcher found that two bare handed practice trials on both dexterity tests were required before an individual's time of completion would stabilize. The two practice trials on both dexterity tests were conducted immediately after briefing, thus prior to any of the glove and static fit evaluations. Although the time of completion for the two trials were recorded, the performance score was based only on the third bare-handed trial completed during the dynamic fit evaluation.

## Measurement of Gloves

Snugness of fit is a factor which has been identified as having a significant relationship with the rate of performance of fine manipulative tasks (Bradley, 1969 a,b). To determine how a garment fits an individual, one must determine the amount of ease provided by the garment design. Ease has been defined as the difference between a wearer's hand and the inside dimensions of the glove (Chapter 1). Therefore, to determine the amount of ease found in each glove type, 11 specific glove dimensions were measured and then compared to each participant's hand dimensions.

The dimensions measured included the circumference of the glove at the point where the fingers meet the palm, the length of the fingers, and the circumference of all of the fingers 2 cm above the crotch markings (Appendix E). The first step in calculating the inner dimensions of the gloves was to measure the outer dimensions.

These figures exceeded the inside dimensions by the thickness of the polymer. The average polymer thickness of individual glove types was therefore measured and subtracted from the outside dimensions. To determine the average thickness of each glove type, three pairs of gloves were measured following CAN/ CGSB 4.2 No. 37 (1987), without added weights.

For example, to determine the inner circumference of the glove at the point where the fingers meet the palm, the outer circumference of the glove was carefully measured to the nearest millimeter with a measuring tape. From this dimension, the outer diameter was calculated and then twice the polymer thickness was subtracted. The inner circumference was then caluculated using the new diameter. This calculation can be summarized with the follow equation:

$$C_i = [D_o - (2 \times T)]\,\pi$$

where $C_i$ = inner circumference
$D_o$ = outer diameter
$T$ = polymer thickness
$\pi$ = constant pi (3.1429).

Finger circumference was measured in a similar manner to hand circumference.

The outer lengths of the glove fingers were measured from the crotch of the fingers near the palm to the tip of each finger. Therefore to calculate the inner length of the fingers, the thickness of the glove polymer was subtracted from the outer dimension only once. The length of the fingers were measured to the nearest 0.5 mm with a ruler. To ensure accuracy of the measurements, two researchers measured the four types of gloves. The level of accuracy for all of the dimensions recorded were within ± 1 mm.

## Statistical Analysis

All data were analyzed using the $Spss^x$ program at the University of Alberta ($Spss^x$ User's Guide, 1986). Background information about the participants and descriptive data about the gloves were summarized by determining frequencies, means and standard deviations. Frequencies were also used to describe comfort ratings and the evaluation of functional fit for each type of glove. Hypotheses 1, 3 and 4 were analyzed using Pearson correlation. One-way analyses of variance were used to test differences in Hypothesis 2 and 5. When significant differences were found, the Scheffé Multiple comparison test determined which pairs of gloves were different. The level of significance for the Scheffé test was set at .10. The level of significance for analyses of variance and Pearson correlations was set at .05.

# IV. FINDINGS

## A. ANTHROPOMETRIC SURVEY

### Description of the Sample

During the months of July and August 1988, a research team travelled to various rural functions throughout Central Alberta to conduct the Anthropometric Survey. Over 400 farmers attending Agricultural Fairs, Alberta Agriculture courses and various organized tours agreed to have 19 specific hand dimensions measured from their dominant hand. In order to participate, farmers were expected to be active grain growers or involved in mixed farming where grain is grown. In reviewing all of the surveys, participants who were either retired or less than 20 years of age, or who had various hand deformations due to arthritis or other illnesses were not included in the sample. A total of 380 surveys were used in defining the user-population's hand dimensions.

### Age Distribution

The age distribution of agricultural workers included in the sample, ranged from 20 to 70 years. The majority of the participants (90.5%) were between 35 and 64 years of age. The mean age was 44.2 with a standard deviation of 12.5. When compared to the 1986 findings from Statistics Canada, the Alberta sample is fairly representative of the entire Alberta farming population (Table 3). The data obtained from this sample can therefore be extrapolated to the general farming population.

Table 3

Age Distribution of Anthropometric Survey Sample Compared to Statistics Canada Data for Alberta.

| Age Category | Anthropometric Survey (N=380) (1988) | Alberta Farm Population Statistics Canada (1986)[a] |
|---|---|---|
| Under 25 | 3.7 % | 2.7 % |
| 25 - 34 | 19.7 % | 17.1 % |
| 35 - 44 | 27.1 % | 22.9 % |
| 45 - 54 | 25.8 % | 24.1 % |
| 55 - 64 | 17.9 % | 21.6 % |
| Over 65 | 5.8 % | 11.6 % |

[a] Table 1-1, Statistics Canada (1986).

### Ethnic Background

The personal information sought during the Anthropometric Survey included the participant's country of origin and ethnic background. Ninety-three percent of the participants were born in Canada. Others were born in Europe (4.2 %), the United States (1.0 %), or other countries (1.6 %). The majority of the participants indicated their ethnic background, however, 3% of the sample did not see the relevance of such information and therefore chose not to give an answer. A total of 28 different ethnic backgrounds were given. Of the 368 who shared this information, 20.5 % were of German decent, 12.1 % were English, 14.6 % were Ukranian or Polish, and 11.3 % gave Canada as their ethnic origin. Participants with various other ethnic backgrounds were each represented by fewer than 6 % of the sample.

**Total Acreage of Farm**

The distribution of farms according to size ranged from less than 50 acres to over 2000 acres. More than half of the participants (59.8 %) reported the total acreage of their farm to be 500 acres or more. The distribution of farms by size among participants is shown in Figure 4.

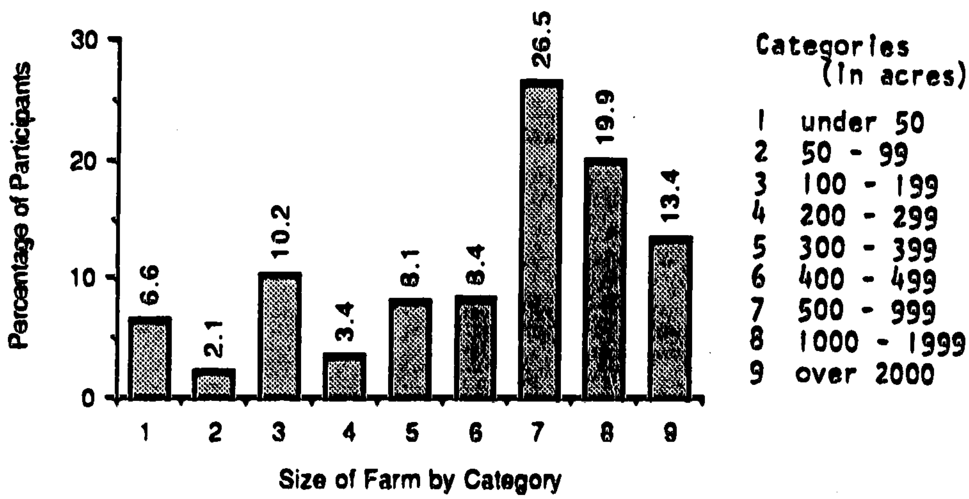


Figure 4. Distribution of Anthropometric Survey Sample by Farm Size.

**Body Dimensions**

Initially, the researcher intended to measure the height, weight, chest and waist of all participants to gather accurate anthropometric data on the body size of Alberta farmers. Due to the nature of the functions where the anthropometric surveys took place, precise measurements of these dimensions were not always feasible. Since accurate records of body dimensions were not essential in defining the hand sizes of grain growers, the researcher chose to ask most of the participants (310) to give their body dimensions verbally.

To represent the size range of the Alberta farming population a relatively wide range of body dimensions was expected. The weight distribution of participants ranged from 51 to 140 kg (125 to 330 pounds). The mean weight was 86.2 kg (190 pounds). The height of participants on the other hand, ranged from 150 to 201 cm (5'0" to 6'9") with a mean height of 179 cm (5' 9"). As expected in population distributions, the curve was close to normal for both body dimensions.

During the first and second anthropometric sessions, farmers who participated agreed to have their chest and waist measured. Unfortunately, when dimensions were requested verbally, many participants did not know their chest and waist sizes. There were therefore only 70 cases in which these dimensions could be observed. Although not necessarily representative of the Alberta population, the following dimensions were found. Participants' chest circumference ranged from 84 cm to 144 cm (33" to 57"). The mean chest circumference was 104 cm (41"). The waist measurements of the 70 participants ranged from 75.6 cm to 142.3 cm (25.5" to 56") with a mean of 96 cm (38").

## Definition of Agricultural Workers' Hand Dimensions

The main objective of the anthropometric survey was to gain some knowledge of the hand dimensions of agricultural workers. The selection of a small sample representative of the user-population could not be chosen for the fit evaluation of protective gloves unless the anthropometric data were available. Along with an illustration and detailed descriptions of the body dimensions that have been measured, it is common practice among anthropometrists to report the mean, the standard deviation, the coefficient of variance and selected percentiles. The statistics for all of the 19 hand dimensions measured during the anthropometric survey are reported in Appendix K.

One of the main arguments for conducting the anthropometric survey was that grain growers would presumably have larger hands than the average population. A comparison with current anthropometric data from a British survey indicates that the agricultural workers from the Alberta survey do in fact have larger hands (Table 4). Except for the length of the middle finger, all dimensions are greater both in length and in width. A comparison of the hand dimensions of agricultural workers with the hand dimensions used by glove manufacturers would be more conclusive in defending this arguement, however, such data were not available to the researcher. The British survey was the most current and detailed data bank available for comparison, although clearly the ethnic mix would presumably differ from the Alberta sample.

Table 4

Comparison of Alberta Agricultural Workers' and British Men's Hand Dimensions

| | Farmers (N=380) | | | | British Men [a] | | | |
|---|---|---|---|---|---|---|---|---|
| Dimensions | 5th %ile | 50th %ile | 95th %ile | SD | 5th %ile | 50th %ile | 95th %ile | SD |
| 1. Maximum spread | 196 | 220 | 246 | 15 | 178 | 206 | 234 | 17 |
| 2. Hand length | 180 | 197 | 215 | 10 | 173 | 189 | 205 | 10 |
| 3. Thumb length | 61.7 | 69.4 | 77.9 | 5 | 44 | 51 | 58 | 4 |
| 4. Index finger length | 68.7 | 76.2 | 84.2 | 5 | 64 | 72 | 79 | 5 |
| 5. Middle finger length | 75.1 | 84.2 | 85.7 | 5 | 76 | 83 | 90 | 5 |
| 6. Ring finger length | 69.5 | 78.1 | 85.7 | 5 | 65 | 72 | 80 | 4 |
| 7. Little finger length | 56.3 | 63.5 | 70.3 | 4 | 48 | 55 | 63 | 4 |
| 8. Hand breadth (thumb) | 98.2 | 108.2 | 117.4 | 6 | 97 | 105 | 114 | 5 |
| 9. Hand thickness [b] | 44.5 | 52.6 | 62.1 | 5 | 44 | 51 | 58 | 4 |
| 10. Thumb diameter | 23 | 25 | 28 | 1 | 20 | 23 | 26 | 2 |
| 11. Index finger diameter | 21 | 24 | 26 | 1 | 19 | 21 | 23 | 1 |

Note: All dimensions are reported in millimeters.

[a] Pheasant, S. 1986. Bodyspace: Anthropometry, Ergonomics and Design. Philadelphia: London, p.126.

[b] Including the thumb.

Care should be taken in interpretation of differences in the length of the thumb. Some variation in the use of landmarks has been found in the literature. While some researchers have chosen the crease closest to the hand as a landmark for the crotch of the thumb, others have used the second crease which appears furthest from the hand. This study chose the former of the two which is the most commonly suggested landmark. The landmarks used in the British survey were not indicated and therefore may be partly responsible for the noted difference.

## B. EVALUATION OF FUNCTIONAL FIT AND COMFORT

The fit evaluation was conducted during the last week of March and the first week of April 1989. Seeding had not yet begun in Alberta, therefore agricultural workers were willing to participate in the study and hoped to increase their knowledge of the types of chemical protective gloves available to them. In spite of the 45 to 60 minutes of intense testing, participants were enthusiastic and expressed a strong interest in the study. Of the 39 volunteers who were scheduled to participate in the evaluation, only one individual did not attend after making an appointment.

### Representativeness of Test Group

The main criteria in the selection of participants for the functional fit evaluation were to ensure the volunteers represented the size range of the user population's hand circumference and length of middle finger. Chapter 3 describes the recruiting procedure and illustrates the representativeness of the small group of participants (Figure 3). Table 5 compares the age and anthropometric data of the test group with the findings from the the Anthropometric Survey (Part A). A total of 38 grain growers was sufficient to adequately represent the key hand dimensions of the agricultural population.

Table 5

Comparison of Fit Test Participants with the Anthropometric Survey Sample

| | Fit Test Participants (n = 38) | | Anthropometric Survey Population (n = 380) | |
|---|---|---|---|---|
| Variable | Mean | S D | Mean | S D |
| Age [a] | 39.5 | 9.5 | 44.2 | 12.5 |
| Estimated Height (inches) | 71.1 | 2.11 | 70.6 | 2.61 |
| Estimated Weight (pounds) | 188.8 | 27.10 | 190.1 | 29.41 |
| Hand Circumference (cm) | 22.4 | 1.10 | 22.6 | 1.16 |
| Length of Middle Finger (cm) | 8.5 | 0.44 | 8.4 | 0.50 |

[a] See Table 6 for age distributions.

## Demographic Information

Participants in the fit evaluation were asked the same general questions requested during the anthropometric survey. They were asked to give their age, country of origin, ethnic background, and size of farm. The age distribution of the participants ranged between 22 and 63 years. The mean age was 39.5 years with a standard deviation of 9.5. Of the 38 participants, however, a large percentage of participants fell in the 25 to 34 years category, and very few participants were in the 55 to 64 and over 65 age groups (Table 6). The other participants were evenly distributed in various age categories. Due to the nature of the dexterity tests, a younger group of participants was not perceived to be detrimental to generalization of findings.

Table 6

Age Distribution of Fit Test Group Compared to the Anthropometric Survey Sample

| Age Category | Fit Evaluation (n=38) | Anthropometric Survey (N=380) |
|---|---|---|
| Under 25 | 5.2 % | 3.7 % |
| 25 - 34 | 36.8 % | 19.7 % |
| 35 - 44 | 25.6 % | 27.1 % |
| 45 - 54 | 26.3 % | 25.8 % |
| 55 - 64 | 5.3 % | 17.9 % |
| Over 65 | 0.0 % | 5.8 % |

All participants but one were born in Canada. The 38 participants came from eleven different ethnic backgrounds. An equal number of participants (18.4 %) were from each of German, Dutch, or Canadian decent. Five participants (13.1 %) were English. Other ethnic groups were each mentioned by three or fewer participants.

The total farm acreage owned by participants ranged from less than 50 acres to over 2000 acres. While some agricultural workers had reduced their farm land to less than 50 acres after many years of farming, the majority of the participants (73.7 %) reported the total acreage of their farm land to be 500 acres or more.

## Background Glove Information

The short questionnaire completed at the end of the fit evaluation was designed to elicit information related to gloves currently being used by agricultural workers, as well as problems participants experienced in purchasing their gloves (Appendix J). Of the 38 participants, 3 were unsure of the glove types they used and one participant reported never wearing gloves. The most common types of gloves reportedly used by 65.8 % (25) of the participants were polyvinylchloride (PVC) and other heavy lined chemical protective gloves. Surgical disposables were the second most popular glove used by 26.3 % (10) of the participants. Twenty-one percent (8) of the test group reported using nitrile gloves. Only a few participants worked with rubber (10.6%) and neoprene (7.9 %) gloves.

When asked to indicate where they usually purchase their gloves, 57.9 % said at UFAs (United Farmers of Alberta), 31.6 % at co-operatives, 23.7 % purchased their gloves at a safety supply store, and 18.4 % at a work wear store. Ten participants experienced no problems when purchasing gloves. Of the 28 participants who experienced problems, 50.0 % complained about limited selection of gloves, while 60.5 % identified poor fit as a major problem. Other problems mentioned were lack of product information (chemical resistance), cost, stiffness of glove polymers and gloves being too short.

The researcher found it interesting to note the number of participants who were familiar with the gloves used in the study (Table 7). While a small number of participants reported seeing gloves similar to Pioneer's 15 and 22 mil nitrile gloves (Gloves A and B), the majority of participants were unfamiliar with the test gloves.

Table 7

Percentage of Participants Familiar with the Test Gloves

| Saw gloves | Glove A | Glove B | Glove C | Glove D |
|---|---|---|---|---|
| Yes | 28.9 % | 34.2 % | 18.4 % | 13.2 % |
| No | 71.1 % | 65.8 % | 81.6 % | 86.8 % |

**Choice of Glove Size**

During the Choice Exercise participants were asked to choose the glove size that offered the best fit. A pair of gloves in each of the four types was selected by all participants. The distribution of participants by glove size indicated that sizes 9 and 10 were most commonly chosen. Of the gloves selected, 50.7 % wore size 10, 36.8 % wore size 9 and 11 % wore size 11. Some variation in individuals' choice of sizes from one glove type to the other was observed, however, the majority of the participants (52.6 %) chose the same size in all four glove types. According to McConville (1986), a minimum of 5 participants is required to test a garment size; since only two participants wore size 8 in the tripolymer glove, the functional fit of this size was not analyzed.

The two key dimensions used in the evaluation of the gloves were hand circumference and length of middle finger. To determine the range of hand sizes accomodated by each glove size, the percentile distribution of hand dimensions of participants choosing each glove size was observed (Figure 5). Size 10 was found to accomodate participants with hand circumferences between the 4 th and 95th percentiles. Although some overlap of hand sizes were found in the distribution for size 9, a narrower range of hand circumferences (from the 3 rd to the 70 th percentile) was accomodated.

When the length of the middle finger was observed, size 9 accomodated a wide range of sizes (from the 8 th to the 90 th percentile). The range of sizes accomodated by Size 10 varied depending on individual types of gloves. Gloves A and D accomodated finger lengths from the 10th to the 99 th percentile. Gloves B and C, however, accomodated finger lengths from the 36 th to the 99 th percentiles.

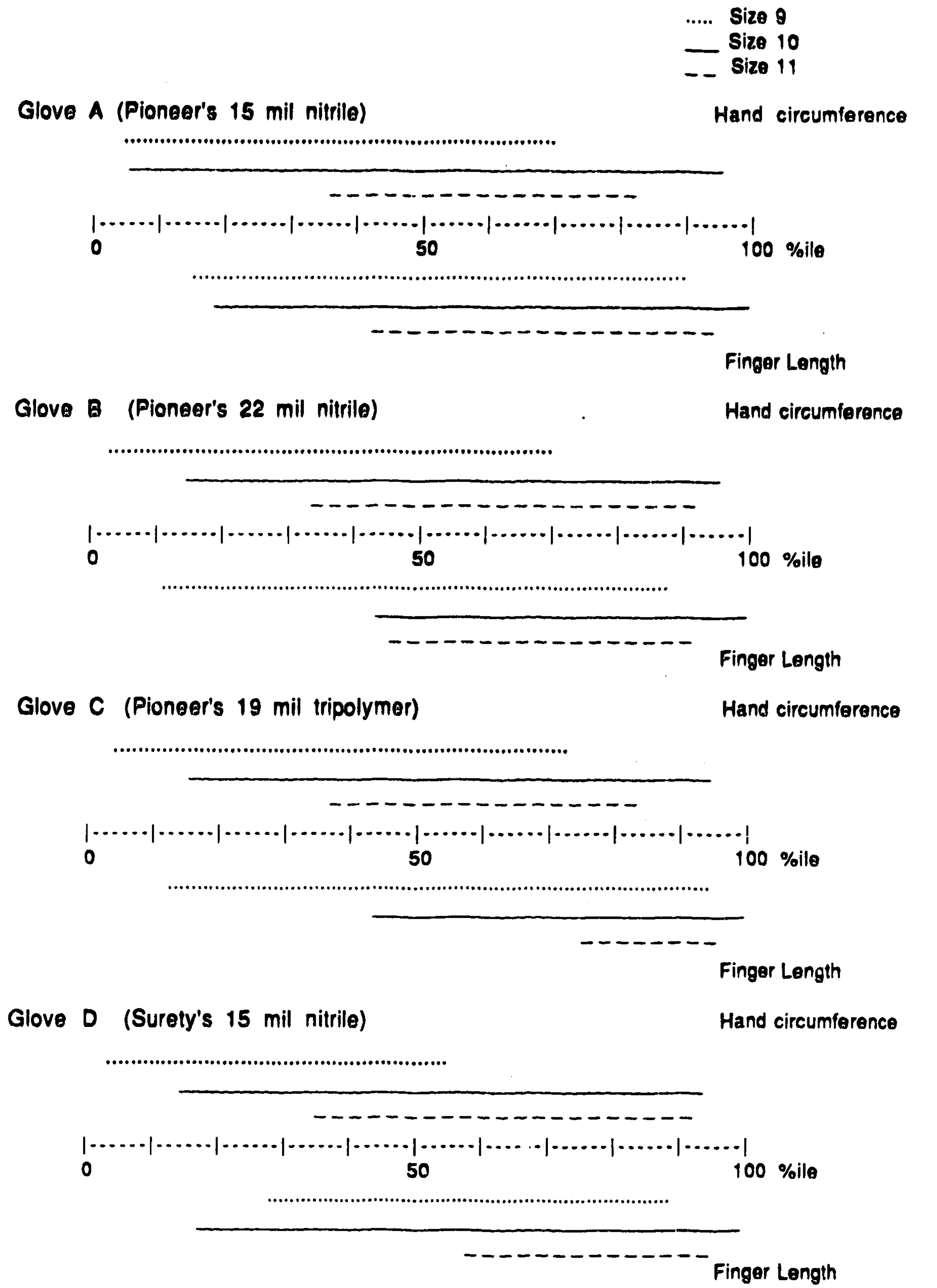


Figure 5. Percentile Distribution of Hand Sizes of Participants Choosing Each Glove Size

**Evaluation of Glove Characteristics**

Following the Choice Exercise, participants were asked to evaluate each type of glove based on four physical characteristics (Questions 1a, b, c, and e of Appendix F). A seven point semantic differential scale was used to evaluate the gloves. Table 8 shows the mean rating for each characteristic by glove type. Pioneer's 19 mil tripolymer glove (Glove C) was described as light, flexible, slightly snug, and having a good fit (5.24). Pioneer's 15 mil nitrile glove (glove A) was also described as light, flexible, and slightly snug, but was described as being neither good nor poor fitting (4.08). Pioneer's 22 mil nitrile glove (Glove B) was described as heavy, stiff, loose and poor fitting. Participants described Surety's 15 mil nitrile glove (Glove D) as neither stiff nor flexible, somewhat light and slightly loose fitting. Glove D was also described as fitting poorly.

Table 8

Mean Ratings of Physical Glove Characteristics

| | Mean Rating | | | |
|---|---|---|---|---|
| Characteristic | Glove A | Glove B | Glove C | Glove D |
| Snugness (loose=1, tight=7) | 4.53 | 2.74 | 4.50 | 3.68 |
| Weight (heavy=1, light=7) | 5.40 | 3.21 | 6.26 | 4.53 |
| Flexibility (Stiff=1, flexible=7) | 5.16 | 2.50 | 6.26 | 4.05 |
| Fit (Poor=1, good=7) | 4.08 | 2.66 | 5.24 | 3.32 |

**Evaluation of Comfort**

To determine the levels of comfort related to the four glove types, participants were asked to rate how comfortable the gloves were during the glove evaluation (question 1d Appendix F). A seven point semantic differential scale was used to measure the comfort evaluations of each type of glove. With uncomfortable given a value of one and comfortable a value of seven, the mean ratings were used to describe the gloves in terms of comfort (Table 9). The comfort values of each glove type ranged from 1 to 7.

Table 9

Comfort Evaluations of Gloves

| | Mean Values | | | |
|---|---|---|---|---|
| Characteristic | Glove A | Glove B | Glove C | Glove D |
| Comfort Rating | 4.55 | 3.05 | 5.42 | 3.68 |
| Estimated time of wear (min.) | 33.7 | 19.9 | 37.6 | 18.8 |

If gloves are acceptable in terms of fit and function, but induce an intolerable amount of discomfort when worn, the gloves will be unacceptable to the user until more acceptable levels of comfort are acheived. To determine the effect of the test gloves on long-term wear participants were asked to estimate how long they thought the average farmer would wear each pair of gloves without removing them (Question II Appendix I). The average estimated time of wear for each glove type served as an indirect measure of comfort (Table 9). Participants estimated being able to wear gloves A and C almost 15 minutes longer than gloves B and D. The average time needed for mixing and loading pesticides may take between 15 to 20 minutes. Under such conditions, all test gloves could be worn for the duration of this task. Gloves B and D would not be acceptable should any task take longer than 20 minutes to complete. Participants found this question particularly difficult to answer; therefore, the validity of the measure is questionable.

## Static Fit

Participants were asked to evaluate 15 specific dimensions for each glove type (Appendix G). From the frequency distribution of participants' descriptions of specific glove dimensions as 'too tight', too loose', or 'just right', major design problems were identified. When 50% or more participants expressed a common complaint about the fit of a particular glove dimension, the fit of the dimension was described as unacceptable to agricultural workers. Frequency distributions of participants in the three response groups were completed for individual sizes and then for all sizes together. Particular design problems occuring only in specific sizes were identified.

Following completion of the two dexterity tests, participants were asked to comment once again on the static fit of the gloves, and to share any additional information related to general glove characteristics. This allowed participants to identify static fit problems perhaps unnoticed during the initial glove evaluation. A total of 53 comments were solicited at this time. General comments about the gloves were noted if mentioned at least five times.

The majority of participants described Pioneer's 15 mil nitrile glove (Glove A), as being too loose around the small finger and too long in the thumb. While 47.4 % of the participants described the middle finger as being too short and the glove too tight when they spread their fingers, other participants felt these dimensions fit 'just right'. Following the dexterity tests, participants described the thumb as being too long and bulky.

The thumb, ring finger, and small finger of Pioneer's 22 mil nitrile glove (Glove B) were all too loose and too long for more than 50 % of the participants. The glove was also described as being too tight when participants spread their fingers. While 42.1 % described the glove as being too tight when they clenched their fist, 44.7 % of the participants described the fit of the glove as being 'just right' . Due to the stiffness of the gloves, participants reported using the wrong fingers to turn the blocks, and unscrewing two screws at once during the Craik Screw test. Once again the thumb was described as being too long.

The only major problem with the tripolymer glove (Glove C) was that the small finger was too loose. Ccmments related to static fit were that the thumb seemed to pucker while manipulating the screws. The glove was described as being slippery due to insufficient surface grip.

The thumb and small finger in Surety's 15 mil nitrile glove (Glove D) were both too loose and too long. A total of 57.9 % of the participants described the glove as being too tight when they spread their fingers. The glove opening was too tight for 50 % of the participants, and just right for the others. Following the dexterity tests, participants described the glove as being difficult to work with, difficult to remove and having too much grip. The thumb which was generally too long, was reportedly complicating fine dexterity.

## Dynamic Fit

To determine the dynamic fit of the gloves, participants' rates of performance while wearing each type of glove were compared to their bare handed performance. The additional time required to complete the dexterity tests while wearing the gloves was indicative of the decrement of performance. To calculate the decrement, the time of completion for the bare handed conditions was subtracted from the time of completion of each glove (glove rate - hand rate = decrement).

Another measure of dynamic fit was determined by calculating the ratio between the standard rate of performance and the glove performance. To calculate the ratio, the time of completion of the glove condition was divided by the bare handed condition. For each glove type, the mean ratios for both dexterity tests were identical. Table 10 indicates the mean measures of dynamic fit for the four glove types.

Table 10

Mean Measures of Dynamic Fit

| | Mean Values | | | |
|---|---|---|---|---|
| Dexterity Test | Glove A | Glove B | Glove C | Glove D |
| Minnesota Rate of Manipulation Test | | | | |
| Ratio (glove/bare hand performance) | 1.3 | 2.1 | 1.2 | 1.7 |
| Decrement (seconds) | 16.22 | 52.97 | 7.97 | 36.25 |
| Craik Screw Test | | | | |
| Ratio (glove/bare hand performance) | 1.3 | 2.1 | 1.2 | 1.7 |
| Decrement (seconds) | 20.18 | 76.07 | 15.52 | 49.82 |

**Subjective Evaluation of Functional Fit**

One of the main objectives in the study was to determine whether the test gloves were functionally designed to meet the needs of agricultural workers. Participants were therefore asked to evaluate the overall goodness of fit of each glove type (Question I, Appendix G). For this evaluation, participants were asked to consider how well the glove fit their hands, as well as their ability to perform while wearing the gloves. The mean rating was used to describe the functional fit of each glove type.

On a scale from 1 to 9, the mean functional fit ratings for Pioneer's 15 mil nitrile glove (Glove A), and 19 mil tripolymer glove (Glove C) were 5.80 and 7.66 respectively. These means indicate that although the overall goodness of fit could be improved, both gloves were acceptable. Pioneer's 22 mil nitrile glove (Glove B) and Surety's 15 mil nitrile glove (Glove D) on the other hand were described as poor fitting with a mean functional fit rating of 2.44 and 3.33 respectively. Both these gloves warrant improvement if they are to be used to complete fine manipulative tasks.

When the functional fit rating for each glove size was observed, size 11 was rated significantly lower than sizes 9 and 10 in all glove types. The overall goodness of fit evaluations of size 11 in all four glove types ranged from 1.5 to 4.6. The quality of fit of the larger glove size should therefore be considered for product improvement.

The evaluations of functional fit reflected participants' choice of preferred glove type (Question III, Appendix I). When asked which glove they preferred to work with, 94.7 % (34) chose the tripolymer glove first. The majority of the 19 participants who were asked to indicate their second, third, and fourth choice, chose Pioneer's 15 mil glove (Glove A) second, Surety's nitrile glove (Glove D) third and Pioneer's 22 mil nitrile glove (Glove B) fourth.

### Glove Dimensions

Chapter 3 describes the method used to measure the inner length of the glove fingers and the inner circumference of the hand and fingers. The polymer thickness of each glove was measured to calculate the inner dimensions of the gloves. The inner glove dimensions for the four types of gloves can be found in Appendix L. In addition to these calculations, polymer thickness was used to ensure the gloves being tested were comparable. Table 11 compares the manufacturers' thickness specifications to the measured thicknesses. Glove A which was .003 of an inch thicker than expected, differed measured thicknesses. Glove A which was .003 of an inch thicker than expected, differed the most from the manufacturer's specification. The other glove types were within ± .0015 of an inch from their specified thicknesses.

Table 11

Comparison of Specified and Measured Polymer Thicknesses

| | Mil (0.001 inches) | |
|---|---|---|
| Glove Type | Measured Thickness [a] | Specified Thickness |
| A | 18.1 | 15 |
| B | 21.6 | 22 |
| C | 20.5 | 19 |
| D | 15.9 | 15 |

[a] The average thickness of three pairs of gloves for each size.

To determine the ease found around the hand and in the length and circumference of the fingers, each participant's hand dimensions were subtracted from the glove dimensions. The resulting differences were used to define ease. The range of values and average ease found in each dimension were used to test null hypotheses 4 and 5.

## C. TESTING OF NULL HYPOTHESES

**Null Hypothesis 1:** There will be no significant relationship between *functional fit* of gloves and participants': a) hand circumference, and b) length of middle finger.

A Pearson correlation analysis for each of the groups of participants wearing sizes 9 and 10 indicated no significant relationship at the set alpha level .05. Neither participants' hand circumference nor the length of their middle finger were significantly related to the functional fit evaluations of the gloves; thus null hypothesis 1 was not rejected.

**Null Hypothesis 2:** There will be no significant difference in *functional fit* (overall goodness of fit), *comfort, static fit* (number of just right), and *dynamic fit* (levels of performance) among the four glove types.

One-way analyses of variance indicated significant differences in the functional fit, comfort, and static fit of the four glove types at $p<.001$ (Table 12). Scheffé's multiple comparison test revealed that the overall goodness of fit of the tripolymer glove (Glove C) was significantly better than Gloves A, B, and D. This finding indicates that a more flexible glove such as Pioneer's tripolymer glove offered a better functional fit than stiffer, nitrile gloves. The functional fit of Pioneer's 15 mil nitrile glove (Glove A) was also found to be significantly better than Gloves B and D. Pioneer's design was therefore preferred over Surety's design, while the thinner nitrile glove was preferred over the thicker polymer.

Table 12

One Way Analysis of Variance in Comfort and Fit Variables Among Glove Types

| | Treatment Means | | | | |
|---|---|---|---|---|---|
| Variables | Glove A | Glove B | Glove C | Glove D | F-ratio |
| Functional Fit (poor=1, good=9) | 5.79 | 2.45 | 7.66 | 3.29 | 61.62 [a] |
| Comfort (uncomf.=1, comf.=7) | 4.55 | 3.05 | 5.42 | 3.68 | 14.80 [a] |
| Static Fit [b] | 9.45 | 6.29 | 11.05 | 8.08 | 18.43 [a] |

[a] $p<.001$
[b] reflects the number of 'just right' responses out of a total of 15.

The mean ratings of comfort obtained during the glove evaluation were used to test this hypothesis (Question 1d, Appendix F). Participants levels of comfort were significantly greater when wearing the tripolymer glove than when they wore Pioneer's 22 mil nitrile glove (Glove B) and Surety's 15 mil nitrile glove (Glove D). The effect of polymer type on comfort was therefore significant when gloves having thicker polymers were compared. A significant difference in the comfort ratings of Pioneer's 15 mil nitrile glove (Glove A) and Pioneer's 22 mil nitrile glove (Glove B) indicated that thinner nitrile polymers were more comfortable than thicker polymers.

The total number of 'just right' responses were tabulated to describe the overall static fit evaluation of each glove type. Scheffé's multiple comparison revealed that polymer type and thickness had an effect on the static fit evaluations of the gloves. The static fit of the flexible tripolymer glove (Glove C) was significantly better than the fit of Pioneer's 22 mil nitrile glove (Glove B) and Surety's nitrile glove (Glove D). Significant differences were also found between Pioneer's 22 mil nitrile glove (Glove B) and both Pioneer's 15 mil nitrile glove (Glove A) and Surety's nitrile glove (Glove D). These findings suggested that thinner nitrile polymer gloves offer a better static fit than thicker gloves irrespective of manufacturers' design differences.

To identify differences in the dynamic fit among glove types, both the decrement of performance (seconds) and the ratio of performance from the two dexterity tests (Minnesota Rate of Manipulation Turning Test and Craik Screw Test) were used in the analysis of variance. Significant differences at the alpha level .001 were found for both measures of dynamic fit. However, Cochran's C test indicated lack of homogeneity in the data. Following Boxcox transformations, homogeneity in the data was established for two of the tests (Sokal & Rohlf, 1981). Significant differences among glove types were identified with both dexterity tests (Table 13).

Table 13

Analysis of Variance of Dynamic Fit Among Glove Types

| Measure of Dynamic Fit | Treatment Means | | | | F-ratio |
|---|---|---|---|---|---|
| | Glove A | Glove B | Glove C | Glove D | |
| **Decrement in Performance (sec.)** | | | | | |
| MRMT[a] Test | 16.22 | 52.97 | 7.97 | 36.24 | 89.36 [b] |
| CS[c] Test[d] | 20.18 | 76.07 | 15.52 | 49.82 | 41.50 [b] |
| **Performance Ratio** | | | | | |
| MRMT Test | 1.33 | 2.08 | 1.17 | 1.73 | 101.45 [b] |
| CS Test[d] | 3.96 | 6.80 | 2.53 | 5.68 | 125.00 [b] |

[a] Minnesota Rate of Manipulation Test.
[b] $p<.001$
[c] Craik Screw Test
[d] Homogeneity of variance not satisfied

When the decrement of performance (seconds) from the Minnesota Rate of Manipulation Test was used to define dynamic fit, significant differences among gloves differing in polymer type, thickness and manufacturers were identified. The extra time needed to complete the block test with the flexible tripolymer glove (Glove C) was significantly less than the time needed with the three nitrile gloves. Significant differences between Pioneer's 15 mil nitrile glove (Glove A) and Pioneer's 22 mil nitrile glove (Glove B) indicated that the turning task was completed significantly faster with thinner gloves than with thicker ones. Finally, significant differences between the dynamic fit of Glove A and D indicated that when wearing Pioneer's nitrile glove participants were able to complete the turning test at a significantly faster rate than when wearing Surety's glove.

Although homogeneity was not obtained after transforming the decrement of performance (seconds) data obtained from the Craik Screw Test, significant differences at $p<.001$ were identified. The significant differences among glove types identified for the turning test apply to the Craik Screw Test. The only exception was that no significant difference was identified between the times required to complete the screw test while wearing gloves A and C.

When the ratio of performance was used to define dynamic fit, the significant differences among glove types discussed for the decrement of performance (seconds) were also observed at $p<.001$. Unlike the previous findings, however, transformations of the original data resulted in homogeneity in the data obtained only from the Craik Screw Test. While no significant differences in the performance ratios on the screw test were found between gloves A and C, significant differences among the other test gloves indicated that thinner more flexible gloves interfered the least with participants' rate of performance. On the basis of the discussed findings, null hypothesis 2 was rejected.

**Null Hypothesis 3:** There will be no significant relationship between the *dynamic fit* (levels of performance) of the gloves and: a) *functional fit* (overall goodness of fit) and b) *static fit* (number of just right).

Pearson correlations for all glove sizes together indicated moderate to strong relationships between the various measures of dynamic fit and both functional and static fit evaluations at an alpha level of .0001. Table 14 indicates the Pearson correlations among these variables. Relatively strong negative correlations were found between decrement of performance and functional fit of the gloves. In other words, as the overall goodness of fit increased, the decrement in performance on both dexterity tests decreased. While relatively strong negative correlations were also found between the levels of performance obtained from the Minnesota Rate of Manipulation test and static fit, only moderate correlations were found between static fit and the dynamic fit obtained from the Craik Screw Test. Following these statistical analyses, null hypothesis 3 was rejected.

Table 14

Pearson Correlations[a] Between Various Measures of Dynamic Fit and Both Functional and Static Fit Evaluations for All Glove Sizes

| Variables | Decrement in performance MRMT[b] | CST[c] | Performance Ratio MRMT[b] | CST[c] |
|---|---|---|---|---|
| Functional Fit | -.64 | -.54 | -.64 | -.52 |
| Static Fit | -.51 | -.39 | -.50 | -.36 |

[a] $p < .0001$
[b] Minnesota Rate of Manipulation Turning test.
[c] Craik Screw Test.

**Null Hypothesis 4:** There will be no significant relationship between the amount of *ease* found in the key dimensions (circumference of the hand at the knuckles and the length of the middle finger) of each glove and: a) *static fit* (number of just right), b) *comfort evaluations,* c) *functional fit* (overall goodness of fit), and d) *dynamic fit.*

Pearson correlation analyses between the amount of ease found in both hand dimensions and all of the listed variables were obtained for sizes 9 and 10 individually and then for all sizes together. Since the findings from all three analyses were similar, Table 15 indicates only the correlations obtained for all sizes together. Weak to moderately strong relationships with a significance level of $p<.05$, were identified between ease and both functional and dynamic fit. Static fit and comfort, however, were only significantly related to the amount of ease found in the length of the middle finger.

Null hypothesis4c and 4d was therefore rejected, while 4a and 4b were only partially rejected.

Table 15

Pearson Correlations Between Ease Found in Key Hand Dimensions and Both Comfort and Fit Variables for All Glove Sizes.

| | Correlation Coefficient ( sig. ) | | | |
|---|---|---|---|---|
| Variables | Hand Circumference | | Tip of the Middle Finger | |
| Static Fit | -.13 | (.060) | -.42 | (.000) |
| Comfort | -.09 | (.122) | -.33 | (.000) |
| Functional Fit | -.23 | (.002) | -.55 | (.000) |
| Decrement MRMT | .19 | (.010) | .67 | (.000) |
| Decrement CST | .17 | (.021) | .54 | (.000) |
| Ratio MRMT | .23 | (.002) | .66 | (.000) |
| Ratio CST | .18 | (.014) | .52 | (.000) |

Comfort, dynamic fit and both static and functional fit evaluations were significantly related to the amount of ease in the gloves. Moderate to strong relationships between the ease found in the length of the middle finger of the gloves and all of the variables were significant at p<.0001. Although very weak, some correlations were found between the ease in the hand circumference, functional fit and the four measures of dynamic fit. Findings indicated that, as the amount of ease increased, the quality of fit of the gloves, participants' rate of performance and levels of comfort decreased.

**Null Hypothesis 5:** There will be no significant differences in the amount of *ease* among *static fit evaluation categories* for specific dimensions of the gloves.

To test this null hypothesis, participants were grouped according to their responses to the quality of fit of each glove dimension. For each type of glove, the mean ease found in the hand circumference and both the length and circumference of the fingers were recorded. These findings along with the frequency distribution of participants in all three response groups are summarized in Tables 16 to 19.

Table 16 <u>Static Fit Evaluations and Mean Ease for Pioneer's 15 mil Nitrile (Glove A)</u>

| DIMENSIONS | | STATIC FIT EVALUATIONS (number of responses) too tight | too loose | just right | MEAN EASE (mm) (range) too tight | too loose | just right | F value |
|---|---|---|---|---|---|---|---|---|
| a) Around the hand | | 5.3% (2) | 23.7% (9) | 71.0% (27) | 18.90 (11.90 - 25.90) | 25.94 (12.10- 48.90) | 27.65 (-4.90 - 54.90) | 0.347 |
| b) Around the fingers: | digit 1 | 5.3% (2) | 36.8% (14) | 57.9% (22) | -0.43 (-5.00 - 4.14) | 9.09 (1.28 - 16.71) | 6.76 (1.28 - 16.71) | 4.249* |
| | digit 2 | 2.6% (1) | 7.9% (3) | 89.5% (34) | --- | 3.05 (-0.43 - 6.86) | 1.46 (-6.72 - 9.00) | 0.283 |
| | digit 3 | 10.5% (4) | 5.3% (2) | 84.2% (32) | 4.00 (-0.72 - 8.71) | 4.57 (-0.72 - 9.86) | 4.09 (-9.79 - 11.89) | 0.010 |
| | digit 4 | 10.5% (4) | 21.1% (8) | 68.4% (26) | 2.72 (-0.43 - 5.86) | 4.73 (-0.43 - 9.00) | 3.53 (-3.57 - 9.21) | 0.509 |
| | digit 5 | 2.6% (1) | 52.6% (20) | 44.7% (17) | - - - | 7.77 (0.86 - 13.43) | 6.10 (-1.07 - 13.43) | 1.265 |
| c) Length of fingers: | digit 1 | 13.2% (5) | 57.9% (22) | 28.9% (11) | -0.35 (-10.77 - 7.54) | 0.16 (-7.07 - 6.33) | 0.53 (-7.24 - 6.56) | 0.081 |
| | digit 2 | 21.1% (8) | 10.5% (4) | 68.4% (26) | -8.08 (-13.37 - 4.66) | -4.65 (-10.87 - -0.66) | -5.76 (-15.44 - 3.84) | 1.555 |
| | digit 3 | 47.4% (18) | 2.6% (1) | 50.0% (19) | -9.64 (-19.27 - -1.56) | - - - | -8.61 (-22.64 - 2.04) | 1.538 |
| | digit 4 | 28.9% (11) | 5.3% (2) | 65.8% (25) | -10.32 (-16.67 - -3.26) | -4.00 (-7.44 - -0.56) | -8.64 (-21.64 - -1.84) | 1.983 |
| | digit 5 | 10.5% (4) | 39.5% (15) | 50.0% (19) | -8.71 (-15.97 - -4.04) | -4.58 (-14.54 - 1.34) | -5.57 (-15.54 - 1.76) | 1.231 |

* $p < .05$

Table 17 Static Fit Evaluations and Mean Ease for Pioneer's 22 mil Nitrile (Glove B)

| DIMENSIONS | | STATIC FIT EVALUATIONS (number of responses) | | | MEAN EASE (mm) (range) | | | |
|---|---|---|---|---|---|---|---|---|
| | | too tight | too loose | just right | too tight | too loose | just right | F value |
| a) Around the hand | | 5.3% (2) | 28.9% (11) | 65.8% (25) | 22.10 (19.60 - 24.60) | 29.49 (7.50 - 54.70) | 25.22 (5.50 - 53.70) | 0.625 |
| b) Around the fingers: | digit 1 | - - - | 86.8% (33) | 13.2% (5) | - - - | 16.65 (2.71 - 28.60) | 16.68 (8.99 - 22.31) | 0.000 |
| | digit 2 | 7.9% (3) | 34.2% (13) | 57.9% (22) | -3.89 (-9.01 - 0.42) | 3.52 (-2.72 - 11.74) | 1.65 (-5.86 - 9.49) | 3.968* |
| | digit 3 | 10.5% (4) | 26.3% (10) | 63.2% (24) | -6.96 (-11.00 - -1.09) | 2.37 (-11.01 - 15.74) | 2.21 (-7.86 - 9.46) | 3.259* |
| | digit 4 | 2.6% (1) | 65.8% (25) | 31.6% (12) | - - - | 7.24 (-6.86 - 18.88) | 3.99 (-3.72 - 12.60) | 1.184 |
| | digit 5 | --- | 84.2% (32) | 15.8% (6) | - - - | 9.93 (-0.43 - 19.17) | 7.89 (2.71 - 12.14) | 0.801 |
| c) Length of fingers: | digit 1 | 2.6% (1) | 86.8% (33) | 10.5% (4) | - - - | 4.46 (-3.34 - 11.23) | 2.09 (-5.87 - 6.94) | 1.379 |
| | digit 2 | 13.2% (5) | 36.8% (14) | 50.0% (19) | -5.84 (-10.44 - -0.76) | 1.77 (-2.04 - 7.26) | -1.07 (-7.94 - 7.74) | 7.195** |
| | digit 3 | 10.5% (4) | 23.7% (9) | 65.8% (25) | -5.25 (-9.94 - -0.86) | 4.78 (1.03 - 7.66) | 1.60 (-4.37 - 7.46) | 12.357*** |
| | digit 4 | 2.6% (1) | 60.5% (23) | 36.8% (14) | - - - | 4.97 (-1.27 - 11.34) | 3.50 (-6.74 - 9.46) | 2.970 |
| | digit 5 | - - - | 92.1% (35) | 7.9% (3) | --- | 5.29 (-6.64 - 15.33) | 3.03 (1.56 - 5.06) | 0.713 |

* p< .05 ** p< .01 *** p< .001

Table 18 Static Fit Evaluations and Mean Ease for Pioneer Tripolymer 19 mil (Glove C)

| DIMENSIONS | | STATIC FIT EVALUATIONS (number of responses) | | | MEAN EASE (mm) (range) | | | |
|---|---|---|---|---|---|---|---|---|
| | | too tight | too loose | just right | too tight | too loose | just right | F value |
| a) Around the hand | | 2.6% (1) | 13.8% (5) | 84.2% (32) | --- | 30.34 (13.60 - 45.50) | 19.98 (-5.20 - 51.50) | 1.972 |
| b) Around the fingers: | digit 1 | 5.3% (2) | 28.9% (11) | 65.8% (25) | -1.53 (-3.10 - 0.04) | 6.98 (1.21 - 12.82) | 4.46 (-4.58 - 12.61) | 3.469* |
| | digit 2 | 5.3% (2) | 5.3% (2) | 89.5% (34) | -1.11 (-5.82 - 3.61) | 1.68 [a] | -0.69 (-15.44 - 7.96) | 0.250 |
| | digit 3 | 10.5% (4) | 2.6% (1) | 86.8% (33) | -2.61 (-11.44 - 3.47) | --- | 1.21 (-10.90 - 9.79) | 1.012 |
| | digit 4 | 2.6% (1) | 10.5% (4) | 86.8% (33) | - - - | 5.41 (2.82 - 9.10) | 1.50 (-7.15 - 8.93) | 1.920 |
| | digit 5 | 2.6% (1) | 50.0% (19) | 47.4% (18) | - - - | 6.50 (-1.18 - 12.36) | 3.39 (-8.87 - 12.36) | 2.289 |
| c) Length of fingers: | digit 1 | 39.5% (15) | 7.9% (3) | 52.6% (20) | -1.34 (-12.83 - 5.50) | -1.47 (-9.13 - 4.40) | -0.48 (-5.83 - 9.50) | 0.204 |
| | digit 2 | 7.9% (3) | 15.8% (6) | 76.3% (29) | -6.96 (-11.43 - -3.30) | -6.97 (-10.53 - -3.19) | -6.35 (-16.00 - -0.83) | 0.143 |
| | digit 3 | 5.3% (2) | 26.3% (10) | 68.4% (26) | -9.58 (-15.33 - -6.50) | -5.64 (-8.29 - -2.99) | -8.78 (-23.90 - -2.40) | 0.807 |
| | digit 4 | 5.3% (2) | 26.3% (10) | 68.4% (26) | -9.07 (-14.23 - -4.30) | -10.09 (-12.59 - -7.59) | -8.93 (-21.20 - -12.30) | 0.093 |
| | digit 5 | 31.6% (12) | 10.5% (4) | 57.9% (22) | -8.73 (-16.53 - -4.10) | -5.98 (-14.63 - 1.31) | -6.61 (-15.60 - 0.56) | 0.557 |

* $p < .05$ [a]same amount of ease for both participants.

Table 19 Static Fit Evaluations and Mean Ease for Surety Nitrile 15 mil (Glove D)

| DIMENSIONS | | STATIC FIT EVALUATIONS (number of responses) | | | MEAN EASE (mm) (range) | | | |
|---|---|---|---|---|---|---|---|---|
| | | too tight | too loose | just right | too tight | too loose | just right | F value |
| a) Around the hand | | 5.3% (2) | 26.3% (10) | 68.4% (20) | 24.20 (18.10 - 30.30) | 39.62 (24.10 - 61.30) | 38.58 (3.10 - 66.10) | 1.218 |
| b) Around the fingers: | digit 1 | 2.6% (1) | 52.6% (20) | 44.7% (17) | - - - | 11.87 (2.36 - 19.67) | 11.95 (2.36 - 23.78) | 2.106 |
| | digit 2 | 2.6% (1) | 15.8% (6) | 81.6% (31) | - - - | 1.95 (-2.36 - 5.67) | 1.98 (-5.50 - 9.93) | 0.825 |
| | digit 3 | - - - | 23.7% (9) | 76.3% (29) | - - - | 9.09 (2.09 - 14.67) | 8.46 (-4.79 - 14.67) | 0.143 |
| | digit 4 | --- | 39.5% (15) | 60.5% (23) | - - - | 6.17 (-0.62 - 17.07) | 4.08 (-3.36 - 9.21) | 2.863 |
| | digit 5 | 2.6% (1) | 63.2% (24) | 34.3% (13) | - - - | 8.68 (0.07 - 17.50) | 6.38 (-3.07 - 14.24) | 1.122 |
| c) Length of fingers: | digit 1 | 10.5% (4) | 63.2% (24) | 26.3% (10) | 0.59 (-2.74 - 4.56) | 1.16 (-16.20 - 13.83) | -1.14 (-12.50 - 8.56) | 0.436 |
| | digit 2 | 10.5% (4) | 34.3% (13) | 55.3% (21) | -2.30 (-4.54 - 1.43) | -1.76 (-10.24 - 6.33) | 2.99 (-12.44 - 1.66) | 0.367 |
| | digit 3 | 13.2% (5) | 18.4% (7) | 68.4% (26) | -1.43 (-5.74 - 3.83) | 4.07 (-6.20 - 11.03) | -0.97 (-16.34 - 5.56) | 3.098 |
| | digit 4 | 7.9% (3) | 39.5% (15) | 52.6% (20) | -2.54 (-6.04 - 1.06) | 0.86 (-8.80 - 11.53) | -3.63 (-15.84 - 6.53) | 3.289* |
| | digit 5 | 2.6% (1) | 86.8% (33) | 10.5% (4) | --- | 3.05 (-13.40 - 14.06) | -0.30 (-6.30 - 5.56) | 0.418 |

* $p < .05$

One way analyses of variance revealed very few significant differences in ease found for each glove dimension among static fit evaluation categories. Participants' responses to the static fit evaluation were generally consistent throughout the glove evaluations. In other words, the majority of the participants identified fit problems in the same glove dimensions. As a result of the consistency in given responses, participants were not well distributed in each of the three groups (*'too tight', 'too loose', or 'just right'* ). To test for significant differences in ease among static fit evaluation categories, a larger number of participants evenly distributed in each of the three response groups would have been needed. Therefore, null hypothesis 5 was not rejected.

From the frequency distribution of participants having described specific glove dimensions as *'too tight', 'too loose', or 'just right'* major design problems were identified. Table 20 indicates the major problem areas identified in all sizes and the mean ease found in the four glove types. To meet the needs of farmers, the fit of these dimensions would have to be improved.

Table 20

Problem Areas by Glove Type

| Dimension by Glove Type | Response (% participants) | | Mean Ease (mm) Problem Group | 'Just Right' Group |
|---|---|---|---|---|
| Pioneer's 15 mil Nitrile | | | | |
| Small finger circumference | too loose | (52.6 %) | 7.77 | 6.10 |
| Length of thumb | too long | (57.9 %) | 0.16 | 0.53 [a] |
| Pioneer's 22 mil Nitrile | | | | |
| Thumb circumference | too loose | (86.8 %) | 16.65 | 16.68 |
| Ring finger circumference | too loose | (65.8 %) | 7.24 | 3.99 |
| Small finger circumference | too loose | (84.2 %) | 9.93 | 7.89 |
| Length of thumb | too long | (86.8 %) | 4.46 | 2.09 |
| Length of ring finger | too long | (60.5 %) | 4.97 | 3.50 [b] |
| Length of small finger | too long | (92.1 %) | 5.29 | 3.03 |
| Pioneer's 19 mil Tripolymer | | | | |
| Small finger circumference | too loose | (50.0 %) | 6.50 | 3.39 [c] |
| Surety's 15 mil Nitrile | | | | |
| Thumb circumference | too loose | (52.6 %) | 11.87 | 11.95 |
| Small finger circumference | too loose | (63.2 %) | 8.68 | 6.38 |
| Thumb length | too long | (63.2 %) | 1.16 | -1.14 |
| Small finger length | too long | (86.8 %) | 3.05 | -0.30 |

[a] Particular problem for glove size 10.
[b] Particular problem for glove size 09.
[c] $p<.05$

The majority of the participants described Pioneer's 15 mil nitrile glove (Glove A), as being too loose around the small finger and too long in the thumb. Pioneer's 22 mil nitrile glove (Glove B) was the least acceptable in terms of static fit. The thumb, ring finger, and small finger were all too loose and too long. The only major problem with the tripolymer glove (Glove C) was that the small finger was too loose. The thumb and small finger in Surety's 15 mil nitrile glove (Glove D) were also described as too loose and too long.

In most cases, when a design problem was identified by the majority of the participants, differences in the mean ease of the satisfied and unsatisfied participants were notable but not statistically significant. The mean ease described as unacceptable (too loose or too long) was between 2 and 3.3 mm greater than the mean ease described as providing an acceptable fit (just right). Not all problems related to the thumb, however, were consistent with this observation. Although the majority of the participants complained that the thumb was too long, very little ease was found at the tip of the thumb. The poor location of the thumb which forced the glove to ride up from the hand, resulted in excess polymer at the tip of participants' thumbs.

T-tests between the 'just right' group and the problem groups (too loose, too long) were used to identify significant differences in the amount of ease found in major problem areas. Except for the tripolymer glove, the amount of ease described as too loose or too long was not significantly different from the amount of ease described as fitting just right. When wearing the tripolymer glove, the amount of ease (6.5 mm) found around the small finger of participants who described the glove as being too loose was significantly different ($p<.05$) from the amount of ease (3.39 mm) described as fitting just right.

## Ease Differences Among Glove Types

Although further research is needed to define an acceptable "ease" value for specific hand dimensions, some differences in the overall mean ease of the four types of gloves were identified. Knowing that participants chose the best fitting glove in each of the four test gloves, the mean ease in specific dimensions can be used to compare the snugness of fit of different types of gloves. Analyses of variance revealed significant differences ($p<.0001$) in the overall mean ease among glove types. Table 21 indicates the mean ease for key glove dimensions for each type of glove.

Table 21

Analysis of Variance of Overall Mean Ease Among Glove Types

| | Mean Ease (mm) | | | | |
|---|---|---|---|---|---|
| Variables | Glove A | Glove B | Glove C | Glove D | F-ratio |
| Hand Circumference | 2.68 | 2.63 | 2.09 | 3.81 | 26.55 [a] |
| Length of Middle Finger | -8.90 | 1.60 | -8.80 | -0.10 | 7.95 [a] |

[a] $p< .0001$

Scheffé's multiple comparison of the mean ease around the hand among glove types revealed significant differences between Glove C and A. The amount of ease found in Pioneer's 15 mil nitrile glove (Glove A) was greater than the amount of ease found in the flexible tripolymer glove (Glove C). A difference in the amount of ease was also found in gloves designed by two different manufacturers. Glove D which was manufactered by Surety, had a significantly greater amount of ease than any of the Pioneer gloves. No significant differences were found between gloves A and B which differed in polymer thickness only.

Significant differences in the amount of ease found at the tip of the middle finger existed between gloves designed by different manufacturers. Significantly more ease was found at the tip of Surety's 15 mil nitrile glove (Glove D) than in either of gloves C and A. More ease was also found in Pioneer's 22 mil nitrile glove (Glove B) than in Pioneer's 15 mil nitrile glove (Glove A), and the flexible tripolymer glove (Glove C).

# V. DISCUSSION

This chapter examines the findings discussed in Chapter 4 as they relate to the objectives and purpose of the study and the literature review. The purpose of the study was to evaluate the functional fit and comfort of commercially available protective gloves recommended to agricultural workers who use pesticides, and to investigate the joint effect of polymer types and thickness of glove materials on fit characteristics. Qualitative and quantitative evaluations of the functional fit of chemical protective gloves by potential users helped identify sizing and design problems related to the poor acceptance of gloves.

## Anthropometric Survey

The first objective of this study was to collect a series of 19 specific hand measurements important in the design of protective gloves, from a large sample of agricultural workers who use pesticides. The hand dimensions of 380 farmers throughout Central Alberta were used to define the user population's hand sizes. Farmers from 28 various ethnic backgrounds participated in the study. A comparison of the age distribution of the anthropometric sample and Alberta's farming population (Statistics Canada, 1986) indicated that the sample was representative of the user population.

Percentile distributions of farmers' hand measurements were completed for the 19 dimensions. Except for the length of the middle finger, the hand dimensions of farmers were found to be larger than the hand dimensions of the average population reported in other studies (Pheasant, 1986). Farmers' finger lengths were 4 to 6 mm longer and 3 mm wider than those of a British sample. The length of farmers' hands were 7 to 10 mm longer than the average population. Although the ethnic variation in the Alberta sample and the British sample clearly differ, the observed differences were greater than one would expect between populations varying only in ethnic background. Further comparisons of the farming sample and the dimensions currently used by glove manufacturers would be essential prior to constructive redesigning of gloves.

The 19 hand dimensions measured in the survey were based on various anthropometric studies interested in the design of gloves (Davies et al., 1980; Courtney,1984). During the fit evaluation, an additional dimension, the length from the crotch of the thumb to the tip of the index finger, was found to be important in the design of gloves. As the majority of participants found the location of the thumb in all gloves less than acceptable, further investigation of the population's thumb location is needed.

## Size Range of Chemical Protective Gloves

Objective two of this study was to determine whether the size range of commercially available chemical protective gloves provided a functional fit for the user-population. The 38 agricultural workers who participated in the study, represented the hand circumference and length of the middle finger of 92 % of the farming population. Although some farmers expressed not being able to find gloves that fit in local stores, and although some gloves were described as unacceptable, participants were all able to complete both dexterity tests with each of the glove types. While the majority of participants (50.7%) chose size 10 as the best fitting size, 36.8 % of the participants chose size 9 and 11 % chose size 11.

Examination of the range of hand dimensions of participants who chose each glove size indicated much overlap in the percentile distribution from one glove size to the next. These findings were indicative of subjective differences in participants' definition of a good fitting glove. Individual responses to comfort and fit of clothing have been described as purely subjective (Sla'∵r, 1986). Due to the variation in hand dimensions within chosen glove sizes, it was not surprising to find that participants' key hand dimensions were not related to the functional fit evaluations of the gloves.

Rather than analyze the functional fit of gloves based on participants' hand dimensions, participants' satisfaction with the overall goodness of fit of their choice of glove size was used to describe whether the size range met the needs of all agricultural workers. Significant differences in the functional fit evaluations among glove sizes suggested a need for improvement in the quality of fit of larger sizes. In all types of gloves, the functional fit evaluations of size 11 were significantly lower than those for sizes 9 and 10. Participants who chose size 11 as the best fitting glove were less satisfied with the overall goodness of fit of the test gloves.

Although 11 % of the participants found the size range of all test gloves unacceptable, the majority of participants (87.5 %) found the size range for both Pioneer's 15 mil nitrile glove and Pioneer's tripolymer glove to be functionally designed to meet their needs. Pioneer's 22 mil nitrile glove and Surety's 15 mil nitrile glove received poor functional fit ratings in all sizes, and therefore were described as unacceptable to the agricultural population.

To be successful, protective gloves should accomodate at least 90 % of the population and aim to suit the need of 98 % (Jürgens,1984). Sizes 9 and 10 in Pioneer's tripolymer and 15 mil nitrile gloves accomodated hand dimensions that ranged from the 5 th to the 95 th percentile. This suggested that 90 % of the user population could possibly find a good fitting glove in the size range currently available in these two glove types. Based on Jürgens' statement, these gloves can be described as meeting the needs of a large portion of the agricultural population. However, whether participants find size 11 to be the only glove large enough for their hand, or prefer a looser fit than that of size 10, agricultural workers who choose size 11 as the best fitting glove will experience many fit problems.

**Evaluation of Various Types of Gloves**

Objectives 3, 4 and 5 were to determine differences in functional fit characteristics among gloves differing in polymer type, material thickness, and manufacturer, and to determine participants' preferences among the four types of gloves. Participants' levels of performance and both static and functional fit evaluations were considered in describing the gloves which were the most acceptable to agricultural workers. Ideally, the acceptable glove must facilitate dexterity and be comfortable to wear (Lyman,1957).

Although some studies (Carlson,1982; Murray,1982) have suggested comfort to be one of the most important attributes in users' acceptance of protective apparel, the functional properties of the gloves seemed more important in participants' evaluations of functional fit. Gloves that fit well and did not interfere with participants' fine dexterity were described as being generally acceptable, for the tasks in this study. These findings were in agreement with Slater's (1985) statement that the functional properties of protective clothing are often the most important attributes in determining a wearer's general state of contentment.

The importance of comfort in participants' acceptance of gloves may have differed under more extreme conditions. While evaluating static and dynamic fit, participants wore the gloves for approximately five minutes at a time. During this short period, participants' hands had begun perspiring. Thermal comfort was not measured in this study, however, one might expect participants' levels of comfort to depreciate as the time of wear increases. Upon wearing the gloves for a longer period of time, the accumulation of sweat inside the gloves would cause the hand to slip and thus interfere with fine dexterity. Under such conditions, comfort would presumably be more influential in participants' evaluation of the functional fit of protective gloves.

Previous studies that have investigated the effects of gloves on fine manipulation have always indentified a measurable decrement in performance between gloved and bare ded conditions (Bradley,1969a; Lyman & Groth,1958; Lyman, 1957). Although gloved hands may not perform as well as bare hands, a reasonable level of performance is expected if gloves are to be worn. The success of protective gloves depends on the extent to which a worker's rate of performance and accuracy are affected.

Significant differences between the dynamic fit of Pioneer's 15 mil nitrile glove and Pioneer's 22 mil nitrile glove suggested that as the polymer thickness increased, participants' rate of performance decreased. Based on the time of completion of both dexterity tests, a 22 mil nitrile glove was found to be unacceptable for fine manipulative tasks, since the average gloved performance was 90% slower than bare handed performance. Differences in the dynamic fit of gloves produced by two manufacturers were also found to affect participants levels of performance. A participant's time of completion while wearing Pioneer's 15 mil nitrile glove was significantly faster than his time of completion while wearing Surety's 15 mil nitrile glove, although the gloves were similar in polymer type and thickness.

The effect of polymer type on dynamic fit was found in the completion of the Minnesota Rate of Manipulation Test. The tripolymer glove which was more flexible than the nitrile gloves allowed participants to complete the block test at a rate comparable to the bare hand condition. Significant differences between the tripolymer glove and Pioneer's 15 mil nitrile glove, were not identified in the completion of the Craik Screw Test, however, this may be explained by Sheridan's (1954) finding that for tasks requiring fine manipulation of small objects such as screws, a polymer which is thin and yet stiff may enhance performance efficiency.

While completing both dexterity tests, significant relationships existed between the static and functional fit evaluations of the four types of gloves and participants' levels of performance. The quality of the fit of chemical protective gloves were directly related to participants' rate of performance. Although highly significant for both dexterity tests, the relationship between static fit and the time of completion of the Minnesota Rate of Manipulation Test were stronger than for the Craik Screw Test. Since the entire hand was manipulated during the block test, the quality of fit of the glove was important in many hand dimensions. The screw test, however, required the use of only three fingers, therefore the fit of other parts of the glove was less important.

For fine manipulation, Pioneer's 19 mil tripolymer glove was preferred over the other test gloves by 93 % of the participants. The tripolymer glove was described as flexible, lightweight, and tight fitting. This glove, which was also described as fitting just right in 11 of the 15 glove dimensions evaluated, allowed participants to complete both dexterity tests at an acceptable performance rate.

Pioneer's 15 mil nitrile glove which was also described as lightweight, flexible and slightly tight fitting, was the second preferred glove. Although poorer in static fit (9 of the 15 dimensions fitted just right), participants were able to perform the two dexterity tests almost as well as with the tripolymer glove; for the Craik Screw test, the differences in decrement of performance for these types of gloves were not significant. Based on participants levels of performance and mean functional fit ratings, it was concluded that Pioneer's 15 mil nitrile glove was acceptable to agricultural workers.

Both Pioneer's 22 mil nitrile glove and Surety's 15 mil nitrile glove received poor functional fit ratings. These gloves, which were described as being heavier and stiffer than Pioneer's 15 mil nitrile and 19 mil tripolymer gloves, were also loose fitting. The gloves fit just right in only 6 and 8 (respectively) of the 15 glove dimensions evaluated. Pioneer's 22 mil nitrile glove and Surety's 15 mil nitrile glove, which were poor fitting, interfered considerably with participants' levels of performance. The time required to complete both dexterity tests increased by 41%

while wearing Surety's nitrile glove, and 91 % while wearing Pioneer's 22 mil glove.

To meet the needs of agricultural workers, chemical protective gloves used for fine manipulative tasks should be relatively flexible, lightweight and tight fitting. By comparing the four test gloves included in this study, thinner 15 mil nitrile gloves were found to be more acceptable than thicker 22 mil nitrile gloves. Thickness, however, became less important when the polymer was more flexible than nitrile. Although similar in thickness and identical in polymer type, the static and functional fit evaluations of Pioneer's 15 mil nitrile glove were consistently greater than Surety's 15 mil nitrile glove.

**Ease, Comfort and Fit Characteristics**

Objective 6 was to determine whether comfort and functional fit characteristics were significantly related to the amount of ease found in key glove dimensions. Generally, participants did not perceive chemical protective gloves as being comfortable. Pioneer's tripolymer glove was the only glove described as somewhat comfortable. Participants described Pioneer's 15 mil nitrile as neither comfortable nor uncomfortable; while Pioneer's 22 mil nitrile and Surety's 15 mil nitrile gloves were both described as fairly uncomfortable.

Others have reported that the thumb and the first two fingers are the most important in fine manipulation (Lyman,1957; Sheridan,1954). The findings of this study that comfort and static fit were related most significantly to the amount of ease found in the middle finger agreed with the previous findings. Excess polymer found at the tip of the glove fingers tended to interfere with participants' skin sensations. The loosely fitted fingers in Pioneer's 22 mil nitrile gloves were particularly detrimental in the successful completion of the dexterity tests. Participants complained of the difficulty in feeling the outer edge of the blocks, and grasping the screws.

The amount of ease found at the tip of the fingers was also related to functional and dynamic fit. Studies have suggested that decrement of performance results from interference of glove materials with cutaneus cues (Groth & Lyman,1958; Sheridan,1954). For fine manipulation, loose fitting gloves were found to be inferior to tighter fitting gloves. Providing a glove does not squeeze the fingers to a state of numbness, a tight fitting glove will increase cutaneous sensations and thus favor a worker's levels of performance.

Although not related to comfort and static fit, the amount of ease found around the hand was significantly related to participants' rate of performance and evaluations of overall goodness of fit. As the amount of ease in the hand circumference increased, participants ability to perform fine manipulative tasks decreased. While wearing Pioneer's 22 mil nitrile glove and Surety's 15 mil nitrile glove, which were described as fitting loosely, participants had a tendency to drop the blocks and screws. Participants' hands also tended to slip inside the loosely fitted gloves. Tichauer & Gage (1978) explained this problem as being caused by poor fit around the hand. Excess bulk in the palm of the hand and near the crotch of the fingers interfere with participants' grasping and bending motions. To hold small objects, workers' had to increase their grasping strength. The time and practice required for participants to adjust to these problems resulted in a decreased rate of performance.

The last objective was to recommend the amount of ease needed in key glove dimensions to accomodate hand size variation among agricultural workers and yet provide a good fit to individual workers. Further research into the ease requirements in chemical protective gloves is needed before specific ease values that meet the needs of all agricultural workers can be determined. From this study, significant mean ease differences were identified among various types of gloves. Polymer type and material thickness were both found to affect the mean ease required to provide farmers with an acceptable fit. A greater amount of ease was consistently found in gloves made from stiff polymers and thick materials.

Major design problems in gloves currently available have been identified and warrant further investigation. The poor location of the thumb was a major problem in all types of gloves. During the static fit evaluation, the majority of the participants described the thumb of the gloves as being too long. Upon calculations of ease, the difference between the dimensions of gloves and participants' thumb were found to be minimal. When asked to force the glove to meet the crotch of their hand, participants generally agreed that the length of the thumb was acceptable. Rather than the thumb being too long, the crotch of the thumb was not deep enough. Since the thumb is particularly important in fine manipulation, repositioning its location would increase workers' rate of performance.

The findings from this study, although not entirely conclusive, have led to mean ease values that have accomodated a wide range of agricultural workers' hand dimensions. When the majority of the participants found the static fit of specific dimensions in a glove to be acceptable, the dimensions of that glove were described as providing sufficient ease to a wide range of agricultural workers. To improve the quality of fit, glove dimensions described as being too loose, would have to be redesigned using the average ease described as fitting 'just right' as a guideline. Fit evaluations with a larger number of participants for individual types of gloves may lead to more descriptive mean values.

# VI. SUMMARY, CONCLUSIONS & RECOMMENDATIONS

## A. SUMMARY

The purpose of this study was to evaluate the functional fit and comfort of commercially available protective gloves recommended to agricultural workers who use pesticides, and to investigate the joint effect of polymer type and thickness of glove materials on fit characteristics. The use of chemical protective gloves has been described as one of the most important means of protection to agricultural workers, since much of the potential pesticide exposure is found on workers' hands. However, gloves currently available are not functionally designed to meet the needs of agricultural workers. Problems related to chemical protective gloves include loss of dexterity, poor fit, and discomfort.

The structure of the study was developed from the Engineering Anthropometric Clothing Design Model. This model illustrates how anthropometric data is incorporated into important stages of both the design and evaluation of functional clothing. One of the important criteria in fit tests is that the test sample represent a wide size range of the user population. The two part study consisted of defining the hand dimensions of the user population (Part A) and evaluating the functional fit of four types of gloves currently available to agricultural workers (Part B).

From anthropometric measurements on 380 farmers, the percentile distributions of agricultural workers' hand dimensions were calculated. Hand circumference and length of middle finger were then used to ensure the representativeness of farmers who participated in the functional fit evaluation. Based on these two hand dimensions, the test group represented the range of sizes of 92 % of the user population.

Four types of gloves differing in polymer type, material thickness and manufacturer were included in the experimental design to determine the effects of thickness and polymer type on fit characteristics. A total of 38 participants evaluated each of the four types of gloves. Participants rated functional fit and comfort by completing the Minnesota Rate of Manipulation Turning Test and the Craik Screw Test.

Pioneer's tripolymer glove received the highest comfort and functional fit ratings. While wearing the flexible tripolymer glove, participants' gloved performance was reduced to 83 % of that of the bare handed performance. One major design problem identified by the majority of the participants was the loose fit in the circumference of the small finger.

Pioneer's 15 mil nitrile glove received acceptable ratings in functional and static fit but was second choice to the tripolymer glove. The nitrile glove was described as neither comfortable nor uncomfortable and had a greater decrement in performance than the tripolymer glove on the Minnesota Rate of Manipulation Test. Major design problems were indentified in the length of the thumb and the circumference of the small finger. Surety's 15 mil nitrile glove was generally less acceptable than Pioneer's 15 mil nitrile glove. Surety's glove which was described as loose fitting, received poor functional and static fit ratings. While wearing this glove, participants' bare handed performance was reduced by almost 50 %. Major design problems were in the length and circumference of the thumb and small finger.

Pioneer's 22 mil nitrile glove was the least preferred of all test gloves. The heavy, stiff and loose fitting glove received poor ratings in comfort, functional and static fit. While wearing the 22 mil nitrile glove, participants' bare handed performance was reduced by 90 %. The circumference and length of the thumb, ring finger and small finger were all described as fitting too loosely.

Although not included in the list of glove dimensions evaluated, the poor location of the thumb in most gloves was an obvious problem noted by the majority of participants. The poor overall goodness of fit of glove size 11 was another problem indentified in all types of gloves.

## B. CONCLUSIONS

The anthropometric approach to the evaluation of chemical protective gloves led to valuable information about specific sizing and design problems that contribute to the poor acceptance of gloves. Careful consideration of both agricultural workers' hand dimensions and the physical properties of glove materials is essential in the successful development of functionally designed protective gloves.

The first part of the study which consisted of the Anthropometric Survey, provided the researcher with percentile data on the range of hand sizes of agricultural workers. Although the main objective of the survey in this study was to ensure the selection of a representative sample for the Functional Fit Evaluation, the data collected will be most useful in the development of future prototype gloves.

During the fit evaluation, the type of polymer, material thickness and the amount of ease found in various types of gloves were all significantly related to functional fit and comfort. Light weight, thin, flexible gloves that fit tightly were generally described as better fitting than heavy, stiff gloves that fit loosely. For optimum performance in completing fine manipulative tasks, a tight fitting glove was preferred to a loose fitting glove.

The thickness of the glove polymer affected participants' levels of comfort, rate of performance, and evaluations of both functional and static fit. For fine manipulation, participants' decrement in performance was significantly greater while wearing the 22 mil nitrile gloves than while wearing the 15 mil gloves. Evaluations of comfort and functional fit characteristics indicated participants' preferences for the thin 15 mil nitrile glove.

Gloves that differed in polymer type but were comparable in polymer thickness were significantly different from one another in all fit characteristics. The flexible tripolymer glove which was described as being more acceptable than the 22 mil nitrile glove was significantly more comfortable, better fitting, and less detrimental to fine manipulation. When compared to the thinner 15 mil nitrile glove, however, significant differences between polymer types were only found in functional fit ratings and the completion time of the block test.

The amount of ease found in the key dimensions of participants' hands was found to be significantly related to static, dynamic and functional fit. As the amount of ease increased, participants' rate of performance decreased. Although the fit of the glove around an individual's hand influenced his evaluations of the overall goodness of fit, a tight fit at the tip of the fingers was particularly important in optimizing fine dexterity.

## C. RECOMMENDATIONS

### For Future Research

1. During the fit evaluation of chemical protective gloves, the poor location of the thumb was a problem noted by many agricultural workers. In order to recommend successful relocation of the thumb, further research should investigate the length between the tip of the index finger and the crotch of the thumb of the user population.

2. To lead to constructive redesigning of gloves or for the development of future prototype gloves, more descriptive data on the mean ease values required to meet the needs of a wide range of agricultural workers' hand sizes are needed. Anthropometric fit

evaluations with a larger number of participants for individual types of gloves should be conducted.

3. This study has investigated the functional fit and comfort problems related to chemical protective gloves used by male agricultural workers only. Many women are becoming involved in handling pesticides and have expressed a concern for the development of gloves that meet their needs. A replication of this study should be conducted with women.

4. During the anthropometric survey and the fit evaluation, the hands of agricultural workers were measured under non-working conditions. Further research into the effects of work on individuals' hand sizes should be conducted to determine whether work affects the fit of gloves.

5. Additional research into product design should be conducted to investigate ways of increasing a worker's rate of performance. For example, reshaping the tip of glove fingers to comform to the human hand, controlling the bulkiness in the joints of fingers and the palm of the hand, and texturing the inner surface of gloves, especially in the fingers might be expected to improve fine manipulation.

### For Manufacturers of Chemical Protective Gloves

1. Since the main goal of protective apparel is to protect a specific population from hazardous environmental conditions, the design should aim to accommodate the range of sizes of 98% of the user population. Glove size 11 was clearly less well designed than glove sizes 9 and 10. To improve agricultural workers' fine manipulation and the overall goodness of fit of gloves, the length of the glove fingers should be shortened.

2. One of the main problems observed during the evaluation of Surety's 15 mil nitrile glove was that the opening of the gloves was too narrow. Participants who could not get their hand into size 9 often complained that size 10 was much too loose. Redesigning the opening of the gloves with consideration to the percentile distribution of agricultural workers' fist circumference and hand circumference may lead to improved functional fit and thus acceptance of the glove.

3. The majority of the participants in this study reported purchasing their gloves in local UFA stores and co-operatives. Despite the variety of gloves currently produced, participants indicated the selection of gloves in these stores to be limited and often available in only one size. Distribution of lightweight, flexible chemical protective gloves in a variety of sizes was a common request expressed by agricultural workers.

### For Agricultural Workers

1. For adjusting nozzles, opening pesticide containers and working with small parts of equipment, a 15 mil flexible protective glove will improve fine dexterity. A glove which fits tightly at the tip of the fingers and fairly snugly around the circumference of the hand will facilitate manipulation of small objects. Heavier neoprene and nitrile gloves should be adopted when mixing concentrates and pouring chemicals into the boom sprayers.

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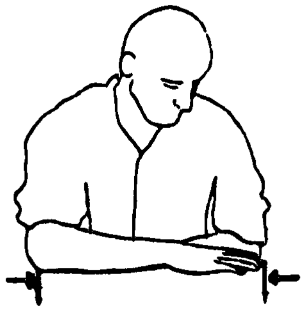
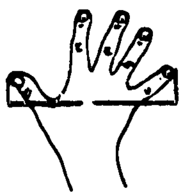
## APPENDIX A

Directions followed by the three researchers who measured the hands of agricultural workers.

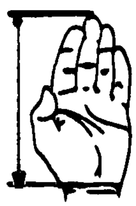
## Directions for the Measurement of the Hand [a]



**FINGER TIP TO ELBOW**: Subject stands with his upper right (left) arm vertical at his side and his forearm, hand, and fingers extended horizontally. Measure the distance from the tip of the elbow to the tip of the longest finger.



**MAXIMUM SPREAD**: Subject spreads the fingers of his hand aligning his small finger and thumb parallel to the ruler. Measure the distance from the tip of his small finger to the tip of his thumb.



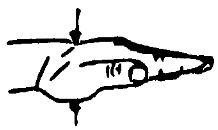
**HAND LENGTH**: Subject's hand is extended, palm up. Measure the distance from the crease of the wrist to the tip of the middle finger (digit 3).

**FINGER LENGTH**: Subject's hand is extended, palm up. With the bar of the sliding caliper lying along the axis of each digit, measure the distance from the tip of each digit to the deep wrinkle formed where the finger folds upon the palm.

**HAND CIRCUMFERENCE (at METACARPALE)**: Subject's hand is extended. With a measuring tape, measure the maximum circumference around the hand just below the crotch of the fingers.

[a] Hertzberg, H.T.E., Daniels, G.S. & Churchill, E. (1954). Anthropometry of Flying Personnel - 1950. WADC Technical Report No. 52-321. Springfield, Ohio: Carpenter Litho and Printing Co.

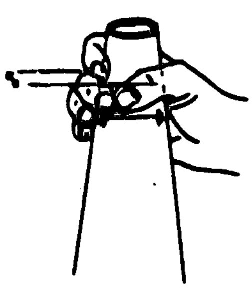
**HAND BREADTH (at THUMB):** Subject's right hand is extended, palm up, with the thumb lying along side and in the plane of the palm. With the bar of the sliding caliper resting on the palm and the caliper's fixed arm at the knuckle of the thumb, measure the breadth at right angles to the long axis of the hand.



**HAND THICKNESS (Including THUMB):** Subject's hand is extended palm down, fingers together with the thumb held against the side of the hand. Using the sliding caliper, measure th maximum depth from the largest part inside the hand to the dorsal surface of the hand.

**FIST CIRCUMFERENCE:** Subject makes a tight fist with his right hand, the thumb lying across the end of the fist. With the tapes passing over the thumb and the knuckles, measure the circumference of the fist.

**FINGER AND THUMB DIAMETER:** One at a time, subject's fingers and thumb are each inserted into a series of graduated holes. Record the diameter of the hole which most closely approximates the maximum diameter of the finger or thumb.



**GRIP DIAMETER:** Subject holds a cone at the largest circumference that he can grasp with his thumb and middle finger just touching.
i) **OUTSIDE:** Using a sliding caliper, measure from the joint of the 1st and 2nd phalange of the thumb (nearest the tip of the thumb) to the knuckle of the middle finger.
ii) **INSIDE:** Using a sliding caliper, measure the diameter of the cone at the midpoint where the finger touched.

## APPENDIX B

**Anthropometric Survey Consent Form**

**and Data Sheet**

University of Alberta
Edmonton
Canada T6G 2M8

Faculty of Home Economics
115 Home Economics Building, Telephone (403) 432-3824



**Code Number** ___ ___ ___

## AGREEMENT AND CONSENT

I, ______________________________, volunteer to participate in a study on the evaluation of fit and comfort of chemical protective gloves by having a series of specific dimensions measured from my hands. I also consent to the recording of my weight, and my chest, waist and height measurements, and the provision of personal background information.

I am aware that the data obtained will be used to evaluate the available sizes of chemical protective gloves used by farmers who apply pesticides. I understand that my identification will be by code number only, and that my personal identity will be kept confidential.

I understand that my participantion is voluntary; I may withdraw at any time.

____________________ Date

______________________________ Signature

If you would like a summary of the final research results, please give your address.

Address: ______________________________________________

______________________________________________

______________________________________________

## ANTHROPOMETRIC SURVEY

No. ___ ___ ___  Observation code ___ ___  Date ________

Location ______________________________

Name: ______________________________
Address: ______________________________
______________________________
______________________________

Age: ____
Birthplace: ____ Canada  ____ U.S.A.  ____ Other
Ethnic Background: ______________________

Total acreage of farm:

| | | | | | |
|---|---|---|---|---|---|
| _____ | under 50 | _____ | 200-299 | _____ | 500-999 |
| _____ | 50-99 | _____ | 300-399 | _____ | 1000-1999 |
| _____ | 100-199 | _____ | 400-499 | _____ | 2000-over |

MEASUREMENTS:

Weight __ __ __  Height __ __ __  Chest __ __ __ cm  Waist __ __ __ cm

Finger tip to elbow ___ ___ . ___ cm
Maximum spread ___ ___ . ___
Hand Length ___ ___ . ___

Digit 1 diameter ___ ___ mm
Digit 2 diameter ___ ___
Digit 3 diameter ___ ___
Digit 4 diameter ___ ___
Digit 5 diameter ___ ___

Digit 1 length ___ . ___ ___ ___ cm
Digit 2 length ___ . ___ ___ ___ cm
Digit 3 length ___ . ___ ___ ___ cm
Digit 4 length ___ . ___ ___ ___ cm
Digit 5 length ___ . ___ ___ ___ cm

Grip diameter (outside) __ . __ __ __ cm
Grip diameter (inside) __ __ . __

Hand width
(across thumb) ___ ___ . ___ ___ ___ cm
Hand thickness
(across thumb) ___ . ___ ___ ___
Hand circumference
(at knuckles) ___ ___ . ___
Fist circumference ___ ___ . ___

Comments:  Grain Grower _____  Other _____

## APPENDIX C

Levels of accuracy among the three researchers who measured farmers' hands during the Anthropometric Survey.

## ACCURACY AMONG THREE RESEARCHERS

| | Deviation from each subject's mean hand dimensions(mm) | | | | | |
|---|---|---|---|---|---|---|
| Hand dimensions | S1 | S2 | S3 | S4 | S5 | Range |
| Finger tip to elbow | ±2.0 | ±4.0 | ±2.6 | ±3.0 | ±3.6 | ±2.0 - ±4.0 |
| Maximum spread | ±1.0 | same | ±1.0 | ±3.0 | ±2.0 | ±1.0 - ±3.0 |
| Hand length | ±1.0 | same | ±1.6 | ±1.0 | ±1.0 | ±1.0 - ±1.6 |
| Digit 1 length | ±1.0 | ±1.2 | ±0.05 | ±1.0 | ±1.0 | ±0.05 - ±1.2 |
| Digit 2 length | ±1.0 | ±1.0 | ±1.0 | ±0.08 | ±0.04 | ±0.04 - ±1.0 |
| Digit 3 length | ±1.5 | ±0.06 | ±0.03 | ±0.08 | ±0.05 | ±0.06 - ±1.5 |
| Digit 4 length | ±1.0 | ±1.0 | ±1.0 | ±1.8 | ±2.0 | ±1.0 - ±2.0 |
| Digit 5 length | ±1.0 | ±0.07 | ±1.0 | ±0.03 | ±1.0 | ±0.03 - ±1.0 |
| Hand width (at thumb) | ±1.0 | ±0.09 | ±1.0 | ±1.6 | ±1.6 | ±0.09 - ±1.6 |
| Hand thickness (at thumb) | ±4.7 | ±1.4 | ±1.7 | ±1.4 | ±1.0 | ±1.0 - ±4.0 |
| Hand circumference | ±6.0 | ±5.0 | ±3.6 | ±0.4 | ±2.0 | ±0.4 - ±6.0 |
| Fist circumference | ±7.0 | ±3.0 | ±4.0 | ±2.0 | ±2.0 | ±2.0 - ±7.0 |
| Digit 1 diameter | ±1.0 | same | ±1.0 | ±1.0 | same | - - - |
| Digit 2 diameter | ±1.0 | same | same | ±1.0 | same | - - - |
| Digit 3 diameter | ±1.0 | same | same | ±1.0 | same | - - - |
| Digit 4 diameter | ±1.0 | ±1.0 | ±1.0 | ±1.0 | ±1.0 | - - - |
| Digit 5 diameter | ±1.0 | ±1.0 | same | same | same | - - - |
| Grip diameter (outside) | ±0.08 | ±0.04 | ±1.0 | ±1.3 | ±1.3 | ±0.04 - ±1.3 |
| Grip diameter (inside)[a] | ±0.5 | ±0.5 | ±0.5 | ±0.5 | same | - - - |

[a] These numbers represent a 0.5 increment on the graduated cone, not millimeters.

## APPENDIX D

Consent Form for farmers who participated in the Functional Fit Evaluation.

University of Alberta
Edmonton

Faculty of Home Economics



Canada T6G 2M8

115 Home Economics Building, Telephone (403) 432-3824

**Code Number ___ ___**

## AGREEMENT AND CONSENT

I, ______________________________, volunteer to participate in a study on the evaluation of fit and comfort of chemical protective gloves.

I consent to having a series of specific hand dimensions measured and the recording of my weight, and my chest, waist and height measurements. I also consent to providing personal background information. I understand that I will be evaluating the fit of four types of protective gloves and will be asked to answer a general questionnaire. I also understand that there is no risk involved in my participation.

I am aware that the data obtained will be used to evaluate the available sizes of chemical protective gloves used by farmers who apply pesticides and that public reports, articles and presentations might be made of this research. I understand that my identification will be by code number only, and that my personal identity will be kept confidential.

I understand that I may withdraw from the study at any time.

____________________ Date

______________________________ Signature

If you would like a summary of the final research results, please give your address.

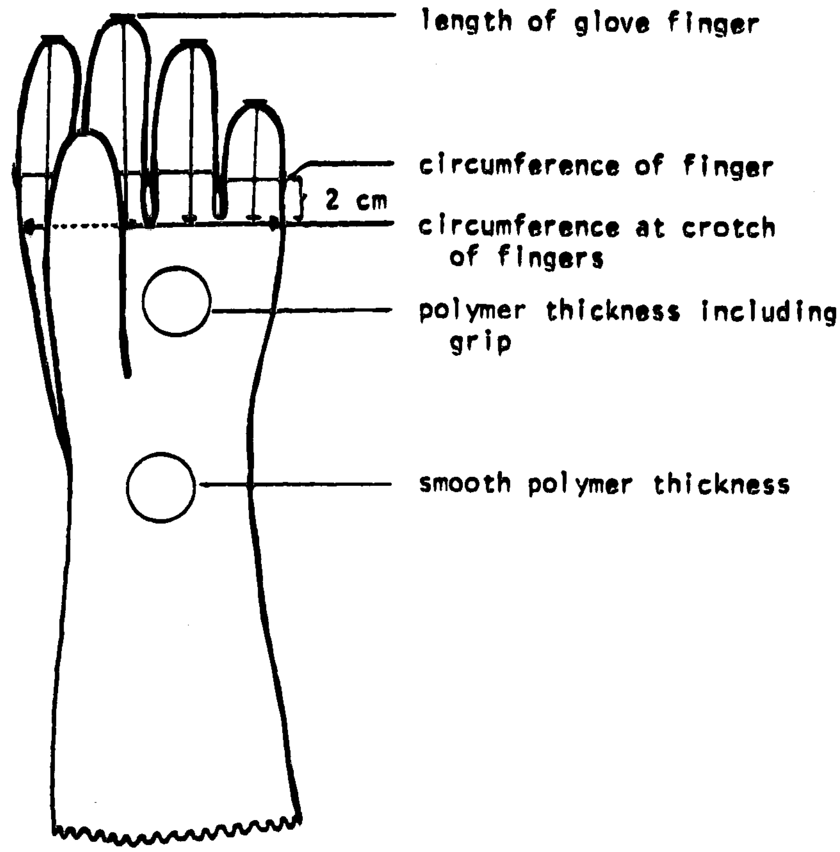
Address: ________________________________________

________________________________________

________________________________________

# APPENDIX E

Meaurement of chemical protective gloves




Measurement of Chemical Protective Gloves

# APPENDIX F

## Choice Exercise and Glove Evaluation

**Code ___ ___ Glove ___**

**CHOICE EXERCISE**

**For each type of glove please choose the size which you feel fits you the best.**

From the three sizes you have before you, select the pair that fits you the best. The task you would have to perform with the chosen gloves includes opening pesticide containers during mixing procedures, as well as adjusting and cleaning nozzles during spraying operations.

Glove Type _____ size _____

**GLOVE EVALUATION**

1. Place a check between each pair of adjectives at the location that best describes the glove that you have chosen.

a) tight fit ___:___:___:___:___:___:___ loose fit

b) heavy ___:___:___:___:___:___:___ light

c) stiff ___:___:___:___:___:___:___ flexible

d) comfortable ___:___:___:___:___:___:___ uncomfortable

e) good fit ___:___:___:___:___:___:___ poor fit

## APPENDIX G

Static Fit Evaluation

Code ___ ___ Glove ___

## STATIC FIT EVALUATION

1. For each of the following dimensions describe the goodness of fit.

| | | too tight | too loose | just right |
|---|---|---|---|---|
| a) around the hand (at the knuckles) | | ___ | ___ | ___ |
| b) around the fingers: | digit 1 | ___ | ___ | ___ |
| | digit 2 | ___ | ___ | ___ |
| | digit 3 | ___ | ___ | ___ |
| | digit 4 | ___ | ___ | ___ |
| | digit 5 | ___ | ___ | ___ |
| c) around the wrist | | ___ | ___ | ___ |

| | | too short | too long | just right |
|---|---|---|---|---|
| d) length of fingers: | digit 1 | ___ | ___ | ___ |
| | digit 2 | ___ | ___ | ___ |
| | digit 3 | ___ | ___ | ___ |
| | digit 4 | ___ | ___ | ___ |
| | digit 5 | ___ | ___ | ___ |

2. How does the glove feel when you clench your fist?
   too tight ____ too loose ____ just right ____

3. How does the glove feel when you spread your fingers as far as you can?
   too tight ____ too loose ____ just right ____

4. How would you describe the opening of the glove?
   too tight ____ too loose ____ just right ____

## APPENDIX H

Dynamic Fit Evaluation

Code ___ ___

## DYNAMIC FIT EVALUATION

| Treatment | Minnesota Test Time (sec.) | Craik Screw Test Time (sec.) | Now that you have completed these tests, would your previous comments on the fit of the gloves change? Or do you have any other comments? No Yes Explain |
|---|---|---|---|
| Trial 1 | | | --- --- --- |
| Trial 2 | | | --- --- --- |
| Bare Hands | | | --- --- --- |
| A-Nitrile 15 | | | |
| B-Nitrile 22 | | | |
| C-Tripolymer | | | |
| D-Surety 15 | | | |

## APPENDIX I

Functional Fit Evaluation and Glove Preference

Code ___ ___ Glove ___

## FUNCTIONAL FIT EVALUATION

I. How would you rate the overall goodness of fit of each glove type you have just tried?

1. Glove A good ___:___:___:___:___:___:___:___:___ poor

2. Glove B good ___:___:___:___:___:___:___:___:___ poor

3. Glove C good ___:___:___:___:___:___:___:___:___ poor

4. Glove D good ___:___:___:___:___:___:___:___:___ poor

II. How long do you think the average farmer would be able to wear these gloves without taking them off ? (ie. Hours or minutes)

Glove A ______ Glove B ______ Glove C _____ Glove D _____

III. Which of the four glove types did you prefer to work with?

Glove A ______ Glove B ______ Glove C _____ Glove D _____

## APPENDIX J

Background Questionnaire

Code ___ ___

## BACKGROUND QUESTIONNAIRE

I. Have you ever seen any of these gloves in the stores?

Yes ____ No ____

If yes, indicate which one(s) Glove A ____ Glove B ____
Glove C ____ Glove D ____

**II. Answer these questions if you have ever used chemical protective gloves.**

1. Where do you usually purchase chemical protective gloves? Check (√) all those that apply.

____ UFA
____ Co-Op
____ a safety supply store
____ a work-wear store
________________ if other please indicate

2. What kind of chemical protective gloves have you worn recently when handling pesticides?

____ Polyvinylchloride
____ Neoprene
____ Rubber
____ Nitrile
____ Disposable vinyl (surgical)
__________________ if other please indicate
____ Unsure

3. Have you experience any problems when purchasing chemical protective gloves?

Yes ____ No ___
If yes, indicate the problem: limited selection ______
poor fit ______
other ________________

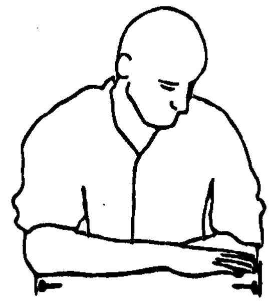
# APPENDIX K

Percentile distribution of agricultural workers' hand dimensions.

(Directions for measurement of hands found in Appendix A)

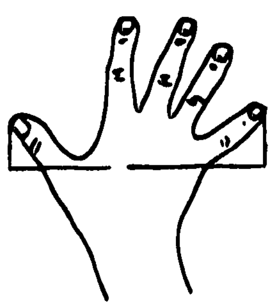
Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 432 | 17.0 |
| 2 | 441 | 17.4 |
| 3 | 446 | 17.6 |
| 5 | 450 | 17.7 |
| 10 | 458 | 18.0 |
| 15 | 463 | 18.2 |
| 20 | 467 | 18.4 |
| 25 | 473 | 18.6 |
| 30 | 475 | 18.7 |
| 35 | 478 | 18.8 |
| 40 | 482 | 19.0 |
| 45 | 485 | 19.1 |
| 50 | 489 | 19.3 |
| 55 | 491 | 19.3 |
| 60 | 495 | 19.5 |
| 65 | 497 | 19.6 |
| 70 | 500 | 19.7 |
| 75 | 502 | 19.8 |
| 80 | 505 | 19.9 |
| 85 | 508 | 20.0 |
| 90 | 512 | 20.2 |
| 95 | 520 | 20.5 |
| 97 | 525 | 20.7 |
| 98 | 532 | 20.9 |
| 99 | 546 | 21.5 |



**FINGER TIP TO ELBOW:**

Mean: 486.91 mm; 19.17 in.
Standard Deviation: 22.46 mm; 0.88 in.
Range: 409-589 mm; 16.10-23.19 in.
V = 4.58 % N = 380



**MAXIMUM SPREAD:**

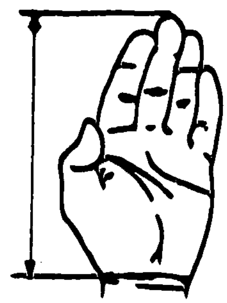
Mean: 220.77 mm; 8.69 in.
Standard deviation: 15.48 mm; 0.61 in.
Range: 172-298 mm; 6.77-11.73 in.
V = 7.01% N = 380

Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 189 | 7.44 |
| 2 | 191 | 7.52 |
| 3 | 192 | 7.56 |
| 5 | 196 | 7.72 |
| 10 | 200 | 7.87 |
| 15 | 204 | 8.03 |
| 20 | 208 | 8.19 |
| 25 | 210 | 8.27 |
| 30 | 212 | 8.35 |
| 35 | 215 | 8.46 |
| 40 | 217 | 8.54 |
| 45 | 219 | 8.62 |
| 50 | 220 | 8.66 |
| 55 | 222 | 8.74 |
| 60 | 225 | 8.86 |
| 65 | 227 | 8.94 |
| 70 | 229 | 9.02 |
| 75 | 231 | 9.09 |
| 80 | 234 | 9.21 |
| 85 | 236 | 9.29 |
| 90 | 240 | 9.45 |
| 95 | 246 | 9.67 |
| 97 | 249 | 9.80 |

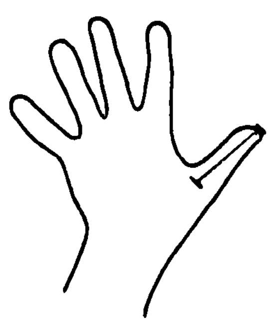
Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 175 | 6.89 |
| 2 | 176 | 6.93 |
| 3 | 178 | 7.01 |
| 5 | 180 | 7.09 |
| 10 | 183 | 7.20 |
| 15 | 187 | 7.36 |
| 20 | 190 | 7.48 |
| 25 | 191 | 7.52 |
| 30 | 193 | 7.60 |
| 35 | 194 | 7.64 |
| 40 | 195 | 7.68 |
| 45 | 196 | 7.72 |
| 50 | 197 | 7.76 |
| 55 | 198 | 7.80 |
| 60 | 199 | 7.83 |
| 65 | 201 | 7.91 |
| 70 | 202 | 7.95 |
| 75 | 203 | 7.99 |
| 80 | 205 | 8.07 |
| 85 | 207 | 8.15 |
| 90 | 209 | 8.23 |
| 95 | 215 | 8.46 |
| 97 | 217 | 8.54 |
| 98 | 219 | 8.62 |
| 99 | 224 | 8.82 |



**HAND LENGTH:**

Mean: 197.31 mm; 7.77 in.
Standard deviation: 10.40 mm; 0.41 in.
Range: 170-250 mm; 6.69-9.84 in.
V = 5.27 % N = 380



**THUMB LENGTH:**

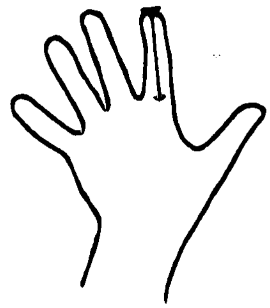
Mean: 69.5 mm; 2.74 in.
Standard deviation: 4.9 mm; 0.19 in.
Range: 50.4-83.7 mm; 1.98-3.30 in.
V = 7.05 % N = 379

Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 58.5 | 2.30 |
| 2 | 59.8 | 2.35 |
| 3 | 60.4 | 2.38 |
| 5 | 61.7 | 2.43 |
| 10 | 63.4 | 2.49 |
| 15 | 64.8 | 2.55 |
| 20 | 65.4 | 2.57 |
| 25 | 66.3 | 2.61 |
| 30 | 66.9 | 2.63 |
| 35 | 67.7 | 2.66 |
| 40 | 68.2 | 2.69 |
| 45 | 68.9 | 2.71 |
| 50 | 69.4 | 2.73 |
| 55 | 70.0 | 2.76 |
| 60 | 70.7 | 2.78 |
| 65 | 71.1 | 2.80 |
| 70 | 71.8 | 2.83 |
| 75 | 72.1 | 2.84 |
| 80 | 73.2 | 2.88 |
| 85 | 74.6 | 2.94 |

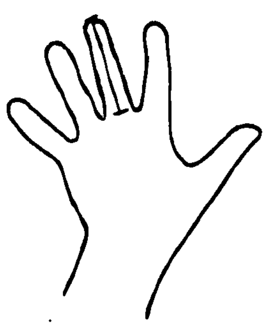
Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 66.2 | 2.60 |
| 2 | 67.0 | 2.64 |
| 3 | 67.7 | 2.67 |
| 5 | 68.7 | 2.70 |
| 10 | 70.4 | 2.77 |
| 15 | 71.6 | 2.82 |
| 20 | 72.3 | 2.85 |
| 25 | 73.2 | 2.88 |
| 30 | 73.9 | 2.91 |
| 35 | 74.8 | 2.94 |
| 40 | 75.4 | 2.97 |
| 45 | 74.9 | 2.99 |
| 50 | 76.2 | 3.00 |
| 55 | 76.8 | 3.02 |
| 60 | 77.4 | 3.05 |
| 65 | 78.0 | 3.07 |
| 70 | 78.7 | 3.09 |
| 75 | 79.4 | 3.13 |
| 80 | 80.4 | 3.17 |
| 85 | 81.3 | 3.20 |
| 90 | 82.2 | 3.24 |
| 95 | 84.2 | 3.31 |
| 97 | 85.7 | 3.37 |
| 98 | 86.6 | 3.41 |
| 99 | 87.8 | 3.46 |



**INDEX FINGER LENGTH:**

Mean: 76.33 mm; 3.01 in.
Standard deviation: 4.73 mm; 0.19 in.
Range: 56.0-88.2 mm; 2.20-3.47 in.
V = 6.20 % N = 380



**MIDDLE FINGER LENGTH:**

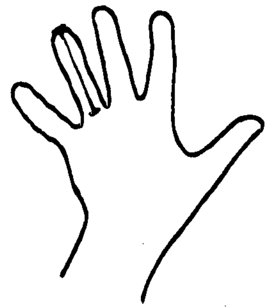
Mean: 83.90 mm; 3.03 in.
Standard deviation: 5.02 mm; 0.20 in.
Range: 68.1-99.2 mm; 2.68-3.91 in.

Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 72.5 | 2.85 |
| 2 | 73.1 | 2.88 |
| 3 | 74.0 | 2.91 |
| 5 | 75.1 | 2.96 |
| 10 | 77.3 | 3.04 |
| 15 | 78.8 | 3.10 |
| 20 | 79.8 | 3.14 |
| 25 | 80.6 | 3.17 |
| 30 | 81.3 | 3.20 |
| 35 | 82.1 | 3.23 |
| 40 | 82.6 | 3.25 |
| 45 | 83.4 | 3.28 |
| 50 | 84.2 | 3.31 |
| 55 | 84.8 | 3.34 |
| 60 | 85.3 | 3.36 |
| 65 | 85.7 | 3.37 |
| 70 | 86.2 | 3.39 |
| 75 | 87.2 | 3.43 |
| 80 | 87.8 | 3.46 |
| 85 | 88.6 | 3.49 |

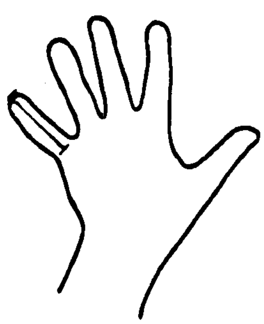
Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 67.0 | 2.64 |
| 2 | 68.0 | 2.68 |
| 3 | 68.7 | 2.70 |
| 5 | 69.5 | 2.74 |
| 10 | 71.8 | 2.83 |
| 15 | 72.8 | 2.87 |
| 20 | 74.6 | 2.94 |
| 25 | 75.2 | 2.96 |
| 30 | 75.7 | 2.98 |
| 35 | 76.4 | 3.01 |
| 40 | 76.9 | 3.03 |
| 45 | 77.7 | 3.06 |
| 50 | 78.1 | 3.07 |
| 55 | 78.6 | 3.09 |
| 60 | 79.4 | 3.13 |
| 65 | 80.0 | 3.15 |
| 70 | 80.6 | 3.17 |
| 75 | 81.3 | 3.20 |
| 80 | 82.0 | 3.23 |
| 85 | 83.1 | 3.27 |
| 90 | 84.3 | 3.32 |
| 95 | 85.7 | 3.37 |
| 97 | 86.8 | 3.42 |
| 98 | 87.1 | 3.43 |
| 99 | 89.0 | 3.50 |



**RING FINGER LENGTH:**

Mean: 78.08 mm; 3.07 in.
Standard deviation: 4.79 mm; 0.19 in.
Range: 59.1-92.9 mm; 2.33-3.66 in.
V = 6.13 % N = 380



**LITTLE FINGER LENGTH:**

Mean: 63.24 mm; 2.49 in.
Standard deviation: 4.49 mm; 0.18 in.
Range: 52.0-85.2 mm; 2.04-3.35 in.
V = 7.10 % N = 380

Percentile Values

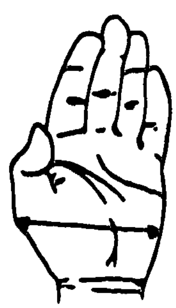
| % | mm | in. |
|---|---|---|
| 1 | 53.1 | 2.09 |
| 2 | 54.0 | 2.13 |
| 3 | 55.2 | 2.17 |
| 5 | 56.3 | 2.22 |
| 10 | 57.5 | 2.26 |
| 15 | 58.3 | 2.30 |
| 20 | 59.2 | 2.33 |
| 25 | 60.3 | 2.37 |
| 30 | 61.1 | 2.41 |
| 35 | 61.6 | 2.43 |
| 40 | 62.1 | 2.44 |
| 45 | 62.8 | 2.47 |
| 50 | 63.5 | 2.50 |
| 55 | 64.0 | 2.52 |
| 60 | 64.5 | 2.54 |
| 65 | 65.0 | 2.56 |
| 70 | 65.5 | 2.58 |
| 75 | 66.1 | 2.60 |
| 80 | 66.6 | 2.62 |
| 85 | 67.4 | [illegible] |

Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 200 | 7.87 |
| 2 | 201 | 7.91 |
| 3 | 203 | 7.99 |
| 5 | 207 | 8.15 |
| 10 | 210 | 8.27 |
| 15 | 213 | 8.39 |
| 20 | 215 | 8.46 |
| 25 | 218 | 8.58 |
| 30 | 220 | 8.66 |
| 35 | 221 | 8.70 |
| 40 | 223 | 8.78 |
| 45 | 224 | 8.82 |
| 50 | 226 | 8.90 |
| 55 | 227 | 8.94 |
| 60 | 229 | 9.02 |
| 65 | 230 | 9.06 |
| 70 | 232 | 9.13 |
| 75 | 234 | 9.21 |
| 80 | 235 | 9.25 |
| 85 | 237 | 9.33 |
| 90 | 240 | 9.45 |
| 95 | 245 | 9.65 |
| 97 | 248 | 9.76 |
| 98 | 250 | 9.84 |
| 99 | 251 | 9.88 |

**HAND CIRCUMFERENCE (at METACARPALE):**

Mean: 225.6 mm; 8.88 in.
Standard deviation: 11.57 mm; 0.46 in.
Range: 196-257 mm; 7.72-10.12 in.
V = 5.13 % N =379

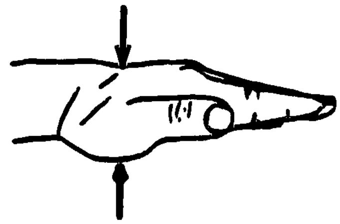


**HAND BREADTH (at THUMB):**

Mean: 108.0 mm; 4.25 in.
Standard deviation: 5.71 mm; 0.22 in.
Range: 90.7-122.6 mm; 3.57-4.83 in.
V = 5.29 % N = 378

Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 92.7 | 3.65 |
| 2 | 96.1 | 3.78 |
| 3 | 96.8 | 3.81 |
| 5 | 98.2 | 3.87 |
| 10 | 100.7 | 3.96 |
| 15 | 102.3 | 4.03 |
| 20 | 103.2 | 4.06 |
| 25 | 104.3 | 4.11 |
| 30 | 105.0 | 4.13 |
| 35 | 105.7 | 4.16 |
| 40 | 106.7 | 4.20 |
| 45 | 107.3 | 4.22 |
| 50 | 108.2 | 4.26 |
| 55 | 108.7 | 4.28 |
| 60 | 109.6 | 4.31 |
| 65 | 110.2 | 4.34 |
| 70 | 111.2 | 4.38 |
| 75 | 112.1 | 4.41 |
| 80 | 112.8 | 4.44 |

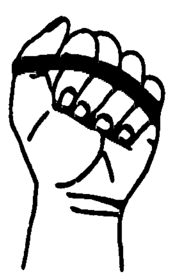


## HAND THICKNESS (across THUMB):

Mean: 52.7 mm; 2.08 in.
Standard deviation: 5.29 mm; 0.21 in.
Range: 41.6-69.1 mm; 1.64-2.72 in.
V = 10.0 % N = 378

Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 42.3 | 1.67 |
| 2 | 42.8 | 1.69 |
| 3 | 42.9 | 1.69 |
| 5 | 44.5 | 1.75 |
| 10 | 46.0 | 1.81 |
| 15 | 46.9 | 1.85 |
| 20 | 47.9 | 1.89 |
| 25 | 48.6 | 1.91 |
| 30 | 49.7 | 1.96 |
| 35 | 50.3 | 1.98 |
| 40 | 51.0 | 2.01 |
| 45 | 51.8 | 2.04 |
| 50 | 52.6 | 2.07 |
| 55 | 53.3 | 2.10 |
| 60 | 54.3 | 2.14 |
| 65 | 55.0 | 2.17 |
| 70 | 55.6 | 2.19 |
| 75 | 56.3 | 2.22 |
| 80 | 57.2 | 2.25 |
| 85 | 58.6 | 2.31 |
| 90 | 59.8 | 2.35 |
| 95 | 62.1 | 2.44 |
| 97 | 62.9 | 2.47 |
| 98 | 63.7 | 2.51 |
| 99 | 65.1 | 2.56 |



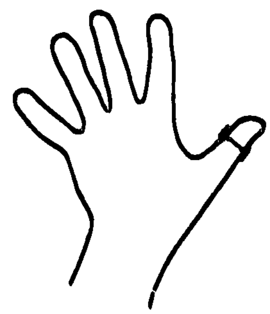
## FIST CIRCUMFERENCE:

Mean: 310.6 mm; 12.2 in.
Standard deviation: 15.5 mm; 0.61 in.
Range: 270-395 mm; 10.6-15.6 in.
V = 4.99% N = 380

Percentile Values

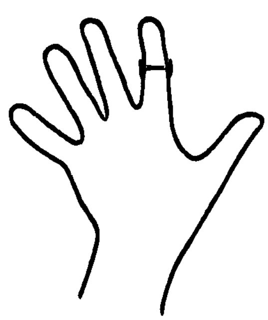
| % | mm | in. |
|---|---|---|
| 1 | 277 | 10.9 |
| 2 | 279 | 11.0 |
| 3 | 282 | 11.1 |
| 5 | 285 | 11.2 |
| 10 | 290 | 11.4 |
| 15 | 295 | 11.6 |
| 20 | 298 | 11.7 |
| 25 | 301 | 11.9 |
| 30 | 303 | 11.9 |
| 35 | 305 | 12.0 |
| 40 | 308 | 12.1 |
| 45 | 309 | 12.2 |
| 50 | 311 | 12.2 |
| 55 | 312 | 12.3 |
| 60 | 314 | 12.4 |
| 65 | 316 | 12.4 |
| 70 | 318 | 12.5 |
| 75 | 320 | 12.6 |
| 80 | 324 | 12.8 |
| 85 | 327 | 12.9 |
| 90 | 332 | 13.1 |
| 95 | 335 | 13.2 |
| 97 | 339 | 13.3 |
| 98 | 341 | 13.4 |
| 99 | 347 | 13.7 |

| Percentile Values | | |
|---|---|---|
| % | mm | in. |
| 1 | 22 | 0.87 |
| 2 | 22 | 0.87 |
| 3 | 23 | 0.91 |
| 5 | 23 | 0.91 |
| 10 | 23 | 0.91 |
| 15 | 24 | 0.94 |
| 20 | 24 | 0.94 |
| 25 | 24 | 0.94 |
| 30 | 24 | 0.94 |
| 35 | 25 | 0.98 |
| 40 | 25 | 0.98 |
| 45 | 25 | 0.98 |
| 50 | 25 | 0.98 |
| 55 | 25 | 0.98 |
| 60 | 25 | 0.98 |
| 65 | 26 | 1.02 |
| 70 | 26 | 1.02 |
| 75 | 26 | 1.02 |
| 80 | 26 | 1.02 |
| 85 | 27 | 1.06 |
| 90 | 27 | 1.06 |
| 95 | 28 | 1.10 |
| 97 | 28 | 1.10 |
| 98 | 28 | 1.10 |
| 99 | 29 | 1.14 |



**THUMB DIAMETER:**

Mean: 25.16 mm; 0.99 in.
Standard deviation: 1.47 mm; 0.58 in.
Range: 21-30 mm; 0.83-1.18 in.
V = 5.84 % N = 380



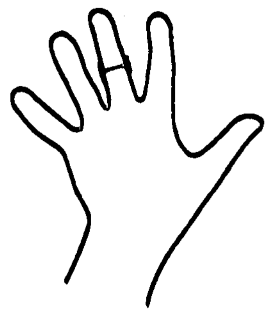
**INDEX FINGER DIAMETER:**

Mean: 23.55 mm; 0.93 in.
Standard deviation: 1.32 mm; 0.52 in.
Range: 20-28 mm; 0.79-1.10 in.
V = 5.61 % N =380

| Percentile Values | | |
|---|---|---|
| % | mm | in. |
| 1 | 21 | 0.83 |
| 2 | 21 | 0.83 |
| 3 | 21 | 0.83 |
| 5 | 21 | 0.83 |
| 10 | 22 | 0.87 |
| 15 | 22 | 0.87 |
| 20 | 22 | 0.87 |
| 25 | 23 | 0.91 |
| 30 | 23 | 0.91 |
| 35 | 23 | 0.91 |
| 40 | 23 | 0.91 |
| 45 | 23 | 0.91 |
| 50 | 24 | 0.94 |
| 55 | 24 | 0.94 |
| 60 | 24 | 0.94 |
| 65 | 24 | 0.94 |
| 70 | 24 | 0.94 |
| 75 | 24 | 0.94 |
| 80 | 25 | 0.98 |
| 85 | 25 | 0.98 |
| 90 | 25 | 0.98 |
| 95 | 26 | 1.02 |
| 97 | 26 | 1.02 |
| 98 | 26 | 1.02 |
| 99 | 27 | 1.06 |

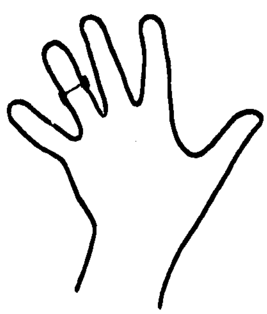
Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 21 | 0.83 |
| 2 | 21 | 0.83 |
| 3 | 22 | 0.87 |
| 5 | 22 | 0.87 |
| 10 | 22 | 0.87 |
| 15 | 23 | 0.91 |
| 20 | 23 | 0.91 |
| 25 | 23 | 0.91 |
| 30 | 23 | 0.91 |
| 35 | 24 | 0.94 |
| 40 | 24 | 0.94 |
| 45 | 24 | 0.94 |
| 50 | 24 | 0.94 |
| 55 | 24 | 0.94 |
| 60 | 24 | 0.94 |
| 65 | 24 | 0.94 |
| 70 | 25 | 0.98 |
| 75 | 25 | 0.98 |
| 80 | 25 | 0.98 |
| 85 | 26 | 1.02 |
| 90 | 26 | 1.02 |
| 95 | 27 | 1.06 |
| 97 | 27 | 1.06 |
| 98 | 27 | 1.06 |
| 99 | 28 | 1.10 |



**MIDDLE FINGER DIAMETER:**

Mean: 24.08 mm; 0.95 in.
Standard deviation: 1.32 mm; 0.52 in.
Range: 21-30 mm; 0.83-1.18 in.
V = 5.48 % N = 380



**RING FINGER DIAMETER:**

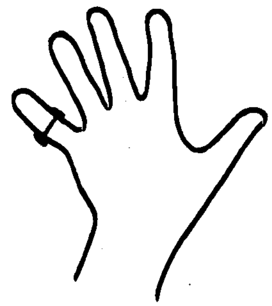
Mean: 22.77 mm; 0.90 in.
Standard deviation: 1.52 mm; 0.60 in.
Range: 20-33 mm; 0.79-1.30 in.
V = 6.68 % N = 380

Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 20 | 0.79 |
| 2 | 20 | 0.79 |
| 3 | 20 | 0.79 |
| 5 | 20 | 0.79 |
| 10 | 21 | 0.83 |
| 15 | 21 | 0.83 |
| 20 | 22 | 0.87 |
| 25 | 22 | 0.87 |
| 30 | 22 | 0.87 |
| 35 | 22 | 0.87 |
| 40 | 22 | 0.87 |
| 45 | 23 | 0.91 |
| 50 | 23 | 0.91 |
| 55 | 23 | 0.91 |
| 60 | 23 | 0.91 |
| 65 | 23 | 0.91 |
| 70 | 23 | 0.91 |
| 75 | 24 | 0.94 |
| 80 | 24 | 0.94 |
| 85 | 24 | 0.94 |
| 90 | 25 | 0.98 |
| 95 | 25 | 0.98 |
| 97 | 26 | 1.02 |
| 98 | 26 | 1.02 |
| 99 | 26 | 1.02 |

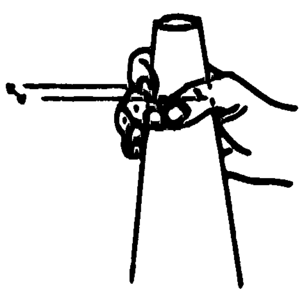
Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 18 | 0.71 |
| 2 | 18 | 0.71 |
| 3 | 18 | 0.71 |
| 5 | 18 | 0.71 |
| 10 | 19 | 0.75 |
| 15 | 19 | 0.75 |
| 20 | 19 | 0.75 |
| 25 | 19 | 0.75 |
| 30 | 20 | 0.79 |
| 35 | 20 | 0.79 |
| 40 | 20 | 0.79 |
| 45 | 20 | 0.79 |
| 50 | 20 | 0.79 |
| 55 | 20 | 0.79 |
| 60 | 21 | 0.83 |
| 65 | 21 | 0.83 |
| 70 | 21 | 0.83 |
| 75 | 21 | 0.83 |
| 80 | 21 | 0.83 |
| 85 | 22 | 0.87 |
| 90 | 22 | 0.87 |
| 95 | 22 | 0.87 |
| 97 | 23 | 0.91 |
| 98 | 23 | 0.91 |
| 99 | 24 | 0.94 |



**LITTLE FINGER DIAMETER:**

Mean: 20.29 mm; 0.80 in.
Standard deviation: 1.30 mm; 0.51 in.
Range: 17-24 mm; 0.67-0.94 in.
V = 6.40 % N = 380



**OUTSIDE GRIP DIAMETER:**

Mean: 91.48 mm; 3.60 in.
Standard deviation: 5.19 mm; 0.20 in.
Range: 55.7-114 mm; 2.19-4.49 in.
V = 5.67 % N = 380

Percentile Values

| % | mm | in. |
|---|---|---|
| 1 | 78.7 | 3.10 |
| 2 | 80.5 | 3.17 |
| 3 | 81.8 | 3.22 |
| 5 | 83.9 | 3.30 |
| 10 | 85.5 | 3.37 |
| 15 | 86.4 | 3.40 |
| 20 | 87.5 | 3.44 |
| 25 | 88.5 | 3.48 |
| 30 | 89.2 | 3.51 |
| 35 | 89.7 | 3.53 |
| 40 | 90.3 | 3.56 |
| 45 | 91.0 | 3.58 |
| 50 | 91.6 | 3.60 |
| 55 | 92.2 | 3.63 |
| 60 | 92.6 | 3.65 |
| 65 | 93.8 | 3.69 |
| 70 | 94.3 | 3.71 |
| 75 | 95.0 | 3.74 |
| 80 | 95.5 | 3.76 |
| 85 | 96.3 | 3.79 |
| 90 | 97.3 | 3.83 |
| 95 | 98.6 | 3.88 |
| 97 | 99.5 | 3.92 |
| 98 | 101.2 | 3.98 |
| 99 | 104.2 | 4.10 |

**Percentile Values**

| % | mm | in. |
|---|---|---|
| 1 | 39.0 | 1.54 |
| 2 | 39.7 | 1.56 |
| 3 | 41.0 | 1.61 |
| 5 | 43.0 | 1.63 |
| 10 | 44.5 | 1.75 |
| 15 | 46.0 | 1.81 |
| 20 | 47.0 | 1.85 |
| 25 | 47.0 | 1.85 |
| 30 | 48.1 | 1.89 |
| 35 | 48.1 | 1.89 |
| 40 | 49.9 | 1.96 |
| 45 | 49.9 | 1.96 |
| 50 | 49.9 | 1.96 |
| 55 | 50.9 | 2.00 |
| 60 | 50.9 | 2.00 |
| 65 | 50.9 | 2.00 |
| 70 | 52.3 | 2.06 |
| 75 | 52.3 | 2.06 |
| 80 | 53.7 | 2.11 |
| 85 | 55.3 | 2.18 |
| 90 | 55.3 | 2.18 |
| 95 | 57.4 | 2.26 |
| 97 | 58.5 | 2.30 |
| 98 | 59.0 | 2.32 |
| 99 | 60.1 | 2.37 |

**INSIDE GRIP DIAMETER:**

Mean: 50.10 mm; 1.97 in.
Standard deviation: 4.23 mm; 0.17 in.
Range: 25.0-37.80 mm; 0.98-1.49 in.
V = 8.62 %  N = 380

## APPENDIX L

Dimensions of the four types of gloves

used to calculate ease.

GLOVE DIMENSIONS USED IN EASE CALCULATIONS [a]

| Glove Dimensions | Mean values (mm) | | | |
|---|---|---|---|---|
| | Size 8 | Size 9 | Size 10 | Size 11 |
| Pioneer's 15 mil nitrile | | | | |
| Hand circumference | - - - | 232.13 | 256.85 | 275.86 |
| Length of thumb | - - - | 65.53 | 67.56 | 72.54 |
| Length of index finger | - - - | 67.53 | 70.56 | 78.54 |
| Length of middle finger | - - - | 70.53 | 77.26 | 85.54 |
| Length of ring finger | - - - | 66.53 | 70.56 | 78.54 |
| Length of small finger | - - - | 54.03 | 59.56 | 64.54 |
| Thumb circumference | - - - | 80.93 | 83.00 | 89.00 |
| Index finger circumference | - - - | 70.93 | 75.00 | 76.00 |
| Middle finger circumference | - - - | 71.93 | 81.00 | 79.00 |
| Ring finger circumference | - - - | 68.93 | 75.00 | 75.00 |
| Small finger circumference | - - - | 64.93 | 70.00 | 69.00 |
| Pioneer's 22 mil nitrile | | | | |
| Hand circumference | - - - | 245.56 | 250.45 | 275.70 |
| Length of thumb | - - - | 70.43 | 71.46 | 79.44 |
| Length of index finger | - - - | 70.43 | 79.76 | 82.44 |
| Length of middle finger | - - - | 81.73 | 89.96 | 90.94 |
| Length of ring finger | - - - | 79.43 | 85.46 | 90.44 |
| Length of small finger | - - - | 69.23 | 68.46 | 70.44 |
| Thumb circumference | - - - | 94.60 | 90.71 | 92.63 |
| Index finger circumference | - - - | 74.60 | 72.71 | 78.63 |
| Middle finger circumference | - - - | 78.60 | 70.71 | 80.63 |
| Ring finger circumference | - - - | 78.60 | 71.71 | 80.63 |
| Small finger circumference | - - - | 72.60 | 68.71 | 74.63 |

[a] inner glove dimensions.

Glove dimensions (cont'd).

| Glove Dimensions | Mean values (mm) Size 8 | Size 9 | Size 10 | Size 11 |
|---|---|---|---|---|
| Pioneer's 19 mil tripolymer | | | | |
| Hand circumference | 207.39 | 231.79 | 256.64 | 272.54 |
| Length of thumb | 59.46 | 63.47 | 70.50 | 67.51 |
| Length of index finger | 63.46 | 69.47 | 70.00 | 76.01 |
| Length of middle finger | 72.46 | 74.47 | 76.00 | 83.51 |
| Length of ring finger | 65.46 | 69.47 | 71.00 | 71.51 |
| Length of small finger | 54.46 | 53.47 | 59.50 | 64.51 |
| Thumb circumference | 70.85 | 78.82 | 82.93 | 84.90 |
| Index finger circumference | 56.85 | 70.82 | 72.93 | 75.90 |
| Middle finger circumference | 60.85 | 70.82 | 78.93 | 78.90 |
| Ring finger circumference | 58.85 | 68.82 | 74.93 | 72.90 |
| Small finger circumference | 50.85 | 64.82 | 68.93 | 68.90 |
| Surety's 15 mil nitrile | | | | |
| Hand circumference | - - - | 240.12 | 267.25 | 287.07 |
| Length of thumb | - - - | 60.10 | 69.56 | 76.63 |
| Length of index finger | - - - | 71.60 | 73.56 | 84.63 |
| Length of middle finger | - - - | 83.60 | 83.56 | 95.63 |
| Length of ring finger | - - - | 74.40 | 76.36 | 90.63 |
| Length of small finger | - - - | 56.60 | 69.56 | 73.13 |
| Thumb circumference | - - - | 80.93 | 88.81 | 96.07 |
| Index finger circumference | - - - | 69.93 | 74.81 | 79.07 |
| Middle finger circumference | - - - | 76.93 | 83.81 | 85.07 |
| Ring finger circumference | - - - | 68.93 | 74.81 | 83.07 |
| Small finger circumference | - - - | 62.93 | 70.81 | 74.07 |