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Cold storage work and cold protective gloves – a review

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ABSTRACT

COLD STORAGE WORK AND COLD PROTECTIVE GLOVES – A REVIEW

by
Daena Charles

The rise of e-commerce and the increasing demand for online grocery shopping and delivery has prompted the growth of warehouse workers subjected to cold temperature working conditions. To ensure food safety and the preservation of inventory, majority of these e-grocery warehouses are cold storage with temperatures from 10°C to -23°C. Exposure to such cold working environments can have effects on the workers comfort, performance and health. As the demand for workers in cold temperature environments increases, it is important to understand how this environment affects the workers and the challenges it may present.

This review evaluates how working in cold temperature work affects the human body in both work ability and productivity. It presents the challenges with using cold weather gloves in cold working environments as it affects dexterity, hand grip and causes fatigue. Selection criteria of cold weather gloves and relevant US and international standards are discussed. Difficulties with using thick gloves in cold temperature on complex tasks are reviewed and alternative solutions suggested to improve employee comfort and productivity.

COLD STORAGE WORK AND COLD PROTECTIVE GLOVES – A REVIEW

by
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APPROVAL PAGE

COLD STORAGE WORK AND COLD PROTECTIVE GLOVES – A REVIEW

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I dedicate this page to my family and friends who have kept me motivated and driven through the completion of my studies. I thank you for your words of encouragement and stern push to keep progressing when I needed it most.

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CHAPTER 1

INTRODUCTION

1.1 Increased Demand for Online Grocery and Cold Storage Workers

The exponential growth in online sales worldwide (Centre for Retail Research, 2014) in the past few years has made online retailing more competitive (Internet Retailer, 2014; Turban et al., 2017) which has led to a surge in online stores not only for retail clothing and electronics but also food purchases. With the rapid growth in sales for large grocery chains who initially only sold non-perishable food items online, it comes as no surprise that these organizations have now branched out to include fresh perishable grocery items for online purchase to their customers. Both online grocery retailers and consumers benefit from this growth. For online retailers, it provides unlimited trading hours, extends geographical reach, enhances customer service, creates faster transactions and shortens product cycles (Wiengarten et al., 2011). For consumers, it provides economic value, access to a wide assortment of products (Hubner et al., 2017), convenience, time savings, fast home delivery and access to a competitive market (Pan et al., 2017). The most recent COVID-19 pandemic further spawned the need and growth of online grocers and delivery service. Customers who were considered ‘high-risk’ for catching the illness and customers who felt unsafe leaving their homes during the pandemic resorted to online retail to support their non-perishable and perishable shopping needs. Online grocery stores and retailers who deliver directly to the consumers door eliminates the need for consumers to leave their home to find quality fresh food for consumption.

Consequentially, as the online grocery market continues to grow, so does the need for workers in cold temperature environments such as walk-in freezers or cold storage warehouses. It is anticipated that the need for cold storage workers will continue to increase as the world population continues to rise, and the need for food preservation through freezers and cold storage is more necessary to accommodate the trend of economic development (Chen et al., 2010). According to the Bureau of Labor Statistics the overall employment in the U.S economy is projected to increase 6.5 percent during the 2014 to 2024 decade; this equates to an addition of approximately 9.8 million new jobs. More specifically, in the major food preparation and serving related occupations, employment is set to rise from approximately 12 million to 13 million employees working in this industry according to these projections (Table 1.1). This increases the refrigerated warehousing working population by 1 million employees.

Table 1.1 Employment and Wages of Major Food Preparation Group, 2014 and Projected 2024 (number in thousands)

2014 National Employment Matrix	Title	Employment		Projected Change, 2014-24		Median annual Wage, 2014
		2014	2024	Number	Percent	
Food Preperation and Serving related occupations	35-0000	12,467.60	13,280.40	812.9	6.5	$19,130

Source: Occupational employment projections to 2024: Monthly Labor Review. (2015, December 01). Bureau of Labor Statistics. Retrieved from https://www.bls.gov/opub/mlr/2015/article/occupational-employment-projections-to-2024.htm

1.2 Conditions of Cold Storage Warehousing

With the anticipated rise in food production, food storage and workers in these cold environments, it is important understand the working conditions of a cold storage warehouse. A significant part of food production, selection, processing and storage in food distribution services requires chilled conditions (Sormunen, 2019) due to hygienic reasons and preservation of products. These chilled conditions can include large buildings; often time warehouses that are kept at constant temperatures between 2°C (35.6˚F) and -23°C (-9.4˚F). From a physiological standpoint, a cold environment can be defined as an environmental condition that activates the thermoregulatory system to reduce heat loss from the body to the environment or that causes uncomfortable sensations of cold (Rintamäki et al., 2005). Additionally, according to the International Standard of Ergonomics in thermal environments, air temperatures of 12 °C or less are also considered a cold indoor environment (BS7915, 1998). These conditions can be found both inside refrigerated warehouse facilities and outside in natural weather.

In addition to steady cold temperatures, workers in cold storage and distribution industries face other indoor environmental factors, such as humidity, air movements, draught and noise, cold working surfaces and handling of cold products (Griefahn et al., 1997). Such cold environments endanger the body's heat balance (Holmér, 2008) and requires internal methods such as thermoregulation or external methods such as the addition of heat retention clothing layers to control heat loss during work. In this review, we will focus on the use of cold weather gloves to retain heat and maintain peripheral body temperature and how use of these gloves may affect the cold storage worker and their overall productivity. But in order to understand the relationship between cold weather glove use and work productivity, we must understand how the body is affected directly by working in such cold environments.

1.3 Study Objective

Exposure to cold working environments is an occupational health hazard that is commonly faced in the growing field of online food grocery and cold warehousing. As the industry continues to grow, so do the number of workers exposed to hazards associated with working in cold environments. Exposure to cold work can pose adverse and long-term effects on the workers comfort, performance and overall health. As the body is affected by decreased muscle temperature or core temperature, physiological factors such as strength, fatigue, endurance, and overall work performance also decreases. Although there is personal protective equipment (PPE) available such as cold weather gloves that reduces the skin and core temperature cooling of the worker, it has been observed that there is a correlation between the decrease of grip strength and productivity with skin temperature cooling and thickness of gloves.

The objective of this thesis is to explore the effects of working in cold environment with a focus on cold weather gloves. The focus of gloves in this review was selected because it has the broadest impact on different roles, tasks and industries. Automated solutions or the use of other technological applications are not being explored in this review. Based on the review of scientific literature, the thesis would present the following:

(1) How working in cold environment affects human body in both work ability and productivity;

(2) Cold weather gloves and its effects on worker productivity in terms of dexterity, hand grip strength and fatigue;

(3) Selection criteria of cold weather gloves and relevant US and international standards; and

(4) Alternative engineering and administrative solutions available to combat the effects of occupational cold hazards.

CHAPTER 2

PHYSIOLOGICAL EFFECTS OF WORK IN COLD ENVIRONMENTS

2.1 Thermoregulation

The human body is maintained at an average temperature of 37 degrees Celsius (or 98.6 degrees Fahrenheit). This allows for optimal cell function and processing; enabling the body to perform normal activities and remain healthy. Human exposure to cold air and environments creates a direct physical hazard to the body and affects how it would normally function. As the human body is required to maintain a specific body temperature to sustain life and physiological functions, thermoregulation occurs when external factors affect the body's ability to maintain its required internal temperature. Thermoregulation is the body's ability to regulate internal temperature in changing climates. The main goal of the thermoregulatory system is to maintain the temperature of the core body which comprises of the brain and organs in the torso to around 37°C (Angelova, 2017). In this process the sensation of coldness is first initiated by cold receptors on the surface of the skin through nerve endings, which then transfers a signal to the hypothalamus located in the brain. This signal is interpreted and responds by sending electrical signals that trigger various thermoregulatory mechanisms. This can include the contraction of muscles, the opening and closing of pores of skin, or changes in breath and heart rate to increase or decrease blood flow to affected parts of the body. When the human body is placed in a cold environment vasoconstriction; defined as a decrease of blood vessels in the surface zones of the skin and extremities, occurs by the smoothing of muscles in the arterioles (Angelova, 2017). Vasoconstriction reduces the amount of heat loss through convection in the skin and preserves the blood to the functions of the heart, lungs and brains. The most severe effects of cold stress are caused by skin cooling. Subsequently, to prevent vasoconstriction from occurring with workers in cold environments, the use of personal protective equipment (PPE) is used to preserve body heat and maintain the maximum functionality and productivity achievable. With clothing being the most common measure to reduce heat loss (Holmér, 2008), it can often be too bulky, restrictive or heavy which in turn affects performance or increases muscle strain and the body's overall workload.

Additional individual factors such as age, body mass, body metabolism and fitness can also influence the human thermal response to the cold. Workers with a larger body size create higher metabolic heat production when compared with smaller individuals (Anderson 1999, Stocks *et al.,* 2004) which allows larger bodies to maintain warmth longer. Older workers may also suffer from preexisting medical conditions such as blood circulation problems with reduced peripheral vasoconstriction and decreased metabolic heat production which would contribute to enhanced heat loss in body temperature even with use of appropriate PPE in cold temperatures. Such factors can impair defense mechanisms that maintain core body temperature and keep the body from becoming susceptible to cold stresses (Kenney & Munce 2003). With any preexisting diminished capacity for internally adjusting to cold working conditions, the health risk factor and likeliness of becoming injured increases.

In some instances where cold exposure has caused vasoconstriction of the blood vessels (which reduces overall heat loss in the extremities), a secondary response called cold-induced vasodilation can occur. When fingers and other extremities are exposed to cold environments, cold induced vasodilatation (CIVD) also occurs where the blood vessels in the skin initially constrict in an effort to prevent heat loss to the surroundings. This is the body's natural way of preventing local cold injuries and retaining dexterity. (Geng, 2001).

2.2 Worker Productivity Impaired by Cold Temperatures

There are multiple ways that cold exposure can affect and reduce a worker's ability to perform occupational tasks efficiently and at a productive rate. Cold exposure places stresses on the body that impair tactile sensitivity, muscle function, finger mobility, speed and reactivity to stimuli and grip strength (Ray *et al,* 2019). These impairments in addition to any other underlying factors that may cause a worker to have increased susceptibility to cold temperatures, decreases the overall performance of the worker. Furthermore, this effect of cold exposure on productivity and performance is dependent on factors such as rate of cooling, the body part cooled and the task specific requirements. In a review by Ray et al (2019) that reviewed cold exposure and manual performance, a general pattern of effects emerged from the studies analyzed: for any given finger's skin temperature, a slower cooling would lead to a longer overall decrease in performance when compared to a faster cooling; cooling of the extremities affects performance more than cooling of the body's core; and manual tasks that are more reliant on the fingers are more greatly affected by cold exposure when compared to the hand, elbow and shoulders. Finger dexterity is more susceptible to decreases in performance following cold exposure when compared to manual dexterity. Additionally, tasks that reply primarily on wrist speed are not affect by the cold exposure as opposed to tasks that are primarily dependent on finger speed (Giesbrecht *et al.,* 1995). In order to understand how this manual performance is affected, it is measured by a combination of many kinds of skills such as hand dexterity, tactile sensitivity, muscle strength and motor coordination. Many of these skills are negatively affected by cooling and even more so when paired with the use of gloves (Imamura et al, 1998).

In cold storage and preparation work there is also a higher prevalence of musculoskeletal complaints which increases with the length of working history in cold environments (Ghasemkhani *and* Rahmat*,* 2012). Epidemiological studies from Chen et al. (1991) show the relation between exposure to cold and the development of some musculoskeletal disorders by linking the increased prevalence of low back pain in cold store work to working in low ambient temperatures. Their research also suggests that shoulder pain is associated with cold or humid working conditions in men.

Due to the numerous factors that may influence how manual performance is affected by cold exposure, it is rather challenging to prove a direct relationship between hand or skin temperature and predicted losses in sensory and motor function (Enander, 1984), but it has been explored in later studies. This also includes the long-term development of musculoskeletal disorders and how it directly correlates to exposure in cold working environments. Older reviews by Enander (1984) reports finger skin temperature thresholds for tactile sensitivity (8 °C) and manual performance to be between 12 and 20 °C (Enander, 1984). The works of Provins and Morton (1960) presents additional evidence that tactile sensitivity is greatly impaired at a finger skin temperature below 8 °C. Their research focused on the relationship between how tactile sensitivity changed as a function of finger skin temperature and was the same across all participants albeit there was variation in each individual's critical temperature threshold. Due to physical sensitivity being critical for manual performance and productivity it is likely that this sudden loss of tactile sensitivity, once the temperature threshold is reached, contributes to the large performance decrements observed at lower hand skin temperatures (Ray *et al*, 2019).

These effects on finger function play an important factor on how cold weather gloves perform or hinder performance. Although the primary function of any PPE is to provide additional protection to the worker from hazardous conditions, the use of cold weather gloves provides another set of limitations to the worker; specifically, decreased dexterity, increased fatigue and overall lower work productivity.

CHAPTER 3

COLD WEATHER GLOVES

3.1 Use of Gloves in Cold Storage Working Conditions

The ability to use one's hands and fingers at optimal functionality is the driving factor in how productive an employee can be in their cold working environment. For this reason, this review focuses primarily on glove use and explores how it affects the workers ability to retain warmth and work at expected productivity rates. In any working environment, hands are the most vulnerable body parts susceptible to short term and long-term damage as they are easily exposed to various hazardous conditions. It is also the body's primary sense of touch and sensitivity and as a result it is a valued body part that requires optimal protection. In cold working environments such as cold storage warehouses, workers are likely to handle frozen materials through cotton gloves or other cold protective gloves and equipment. Regardless of the type of glove that is worn, fingers and hands come into direct contact with frozen products. Even though this exposure is rarely at a long period of time, fingers and hands are the body parts repeatedly and intermittently cooled with the rest of the body at minimal repetitive exposure (Sawada et al., 2000).

Due to its importance not only for everyday tasks but to complete dexterous work, gloves are designed to protect the hands from various injuries with the notion that 'the thicker the glove, the better the protection' (Chih-Hung and Yuh-Chuan, 2006). This approach in glove design can lead to changes in hand dimensions, hand volume and thickness (Damon rt al., 1966) and increases the force required to move fingers in thick gloves. Manual dexterity, fatigue, the increased risk of developing musculoskeletal disorders and affects to performance and comfort are all concerns for workers in cold temperature environments. When selecting appropriate gloves for cold working environments, selection should be made considering adequate insulation properties, gloves design, textiles and other insulating properties that would provide not only protection, but maximum functionality.

In the cold food storage industry, one can find work that is both high intensity and requires constant movement with use of the entire body or static work where the body remains relatively unmoved during the shift. Both types of work can influence the type of PPE necessary for use. Work conducted in fixed positions (or static work) such as employees using heavy machinery, transportation, sitting or standing stationary tasks, or any function with limited movement (Angelova, 2017) can cause blow flow to be reduced and adds additional stress to the body. While working in cold conditions with limited movement a glove with minimal dexterity and can be harmful and should be avoided. Current gloves on market for freezing temperatures cater more to tasks that require minimal intricate hand movement than the latter. On the other hand, many of the online grocery stores that store and select items individually to be packaged for customer deliveries require fine motor stills which increases the demand for cold weather gloves that provide high dexterity and functionality while retaining finger warmth. Regardless of how much a cold weather glove may be marketed toward providing high functionality and warmth, the presence of any cloth or material between an individuals fingers and an object that operates in a freezing working environment, there is a relationship between glove thickness, grip strength and hand fatigue; leading to reduced worker productivity.

3.2 Glove Thickness Effect on Grip Strength

Previous studies show that gloves reduce both sensitivity and range of hand movement and reduces the grip maximum voluntary contraction or MVC (Chih-Hung and Yuh-Chuan, 2006); a standardized method of measuring muscle strength. Chih-Hung and Yuh-Chuan (2006) investigated the effects of glove thickness on hand performance and fatigue during high frequency tasks. They evaluated hand performance by studying the MVC and the associated time needed to reach to reach this MVC. The study also evaluates the total force generation during the sustained tasks. Ten voluntary female participants free of musculoskeletal disabilities on the upper extremities participated in the study. Using a grip gauge to measure force output and cotton gloves commonly applied in industrial workplaces (1.1 mm thick), participants were asked to grip the gauge with either no gloves, one glove, two layers of cotton gloves or two gloves held in the hand but not worn; using only their dominant hand. The subjects were asked to squeeze the grip gauge or exert force enough to reach their peak strength as quickly as possible and then to maintain that strength for 5 seconds or until they were unwilling or unable to sustain it further. This maximal duration of exertion or

MET period from the beginning of the rested state to the halt of force exertion corresponding to the sustained gripping would be called the MET. Once this initial task was completed, the MVC was then measured using the same gloved condition. This process would be repeated for a total of eight treatments and 2 replications (a total of 16 tests).

Using a statistical MANOVA factorial design for experimentation and calculation of the results, the total force generated (TFG) was shown to decrease with the increased number of gloves worn. The bare-handed test held the best hand performance, while the three gloved tests had the worst performance; the 2-layer of gloves worn held the worst TFG. The study concluded that force generation is affected by glove thickness and not wearing style.

Another glove thickness experiment conducted by Bensel (1993) explored the relationship between the thickness of a hand covering and its effect on manual dexterity. In this experiment, twelve men performed five dexterity tests while barehanded, and while wearing three different thicknesses of protective gloves; 0.18 mm, 0.36 mm, and 0.64 mm. The five dexterity tests include (1) Minnesota rate of manipulation-turning, (2) the O'Connor finger dexterity, (3) the Cord and Cylinder manipulation, (4) The Bennet hand-too dexterity, (5) and the Rifle disassembly/ assembly (Bensel, 1993). Each dexterity test was performed two times in each thickness of glove, or no glove, in a series of 13 sessions that occurred on the same day of every week. All subjects performed the dexterity tests in the same order. Using statistical analysis or ANOVA to interpret the results from each dexterity test, results showed that in fine-finger manipulations, bare-handed times for completion of the test far exceeded those of the 0.64 mm thick gloves. The various dexterity tests concluded that multiple layers of gloves impaired touch sensitivity, and greater grip and load force were required when multiple layers of gloves were worn to pick up targets of different weights or required finger dexterity to complete finer tasks. Seeing as performance levels in the manual tests declined as thickness increased, this suggests that with respect to worker productivity, the thickness of gloves plays an important factor in PPE selection. Thicker gloves reduce the speed with which work could be completed.

Manual dexterity is a motor skill that includes the entire arm hand and fingers and is formed by a combination of reaction time, receptivity, nerve conduction, grip strength, time to exhaustion, and mobility. Low temperature affects this manual dexterity due to lack of thorough warming of the fingers while wearing cold temperature gloves. Low temperature in addition to the thickness of material in joints of the fingers from gloves, places an additional strain on the hand muscles and reduces manual dexterity. One example of an experiment by Yinsheng et al. (2018) explored the effects of extravehicular activity (EVA) gloves on manual dexterity in low temperatures and low-pressure environments. Using a Purdue pegboard and nut fastening test, dexterity was assessed by analyzing the times for completion at various temperatures and pressures. Results for the experiment showed that completion times for both tests increased as temperature decreased, when pressure increased and under combined conditions, indicating an interactive relationship between low temperature and pressure (Yinsheng, 2018).

3.3 Effects of Cold Weather Gloves on Hand Fatigue

As beforementioned, one of the effects of wearing cold weather gloves in extremely cold environments is the additional force and strength required by the user to perform ordinary tasks. This causes hand fatigue to increase which in turn has a direct effect on the rate of productivity with hand work. Another study by Yinsheng et al. (2016) in Beijing China explores the effects of wearing extravehicular activity (EVA) gloves on grip strength and fatigue in combined factors: low pressure and low temperature. EVA gloves are primarily used in astronaut operations in outer space and serve as the most outer layer of PPE protection for astronauts.

Using ten male university volunteers, the team conducted maximum grip strength and fatigue tests in five experimental groups. The five experiment groups included three variables: pressure, ambient temperature and grip bar surface temperature and were conducted in a low-temperature simulation cabin designed for EVA gloves. In order to measure grip strength, volunteers were asked to grip a dynamometer or grip acquisition system that is used to acquire and display real-time values of recorded grip strength. When the dynamometer is touched and pressed, pressure signals are received by pressure sensors that transform into voltage signals that generate grip strength data. The averaged grip strength values are then calculated and recorded as the subject's maximum grip strength.

During the experiment, subjects are asked to put their hand into the glove that is connected to pressure sensors. They then proceed to grab the dynanometer while in a seated position with appropriate height to avoid adding additional stressors such as pull and push. The subjects grab the dynamometer uniformly with a frequency of 5 times every 30 seconds using their maximum strength. Each grasp should last 10 seconds with 30% maximum grip strength; labeled as F_{max}. This is repeated until at least two out of five times, the grip value falls below 50% of F_{max} or less than 15% maximum grip strength.

It is important to note that although pressure plays a large role of this experiment, pressure is not a current factor in cold storage warehouses. Out of the five experimental groups, Treatment Group II focuses on the effect of low temperature on grip fatigue; no pressure. The results from this group revealed that grasping low-temperature objects affected grip strength significantly when compared to the control group at 25˚C. Figure 3.1 shows that at 25˚C, working capacity is at 100%. This working capacity used to determine fatigue is defined as the total volume of work you can perform, recover from and adapt positively to. At temperatures from -50 to -130 degree Celsius the working capacity was reduced 50% on average. However, between working capacity or fatigue in the colder temperatures there were small differences. It was concluded that due to finger temperature, tingling, stiffness and other stress reactions the amount of working time decreased.

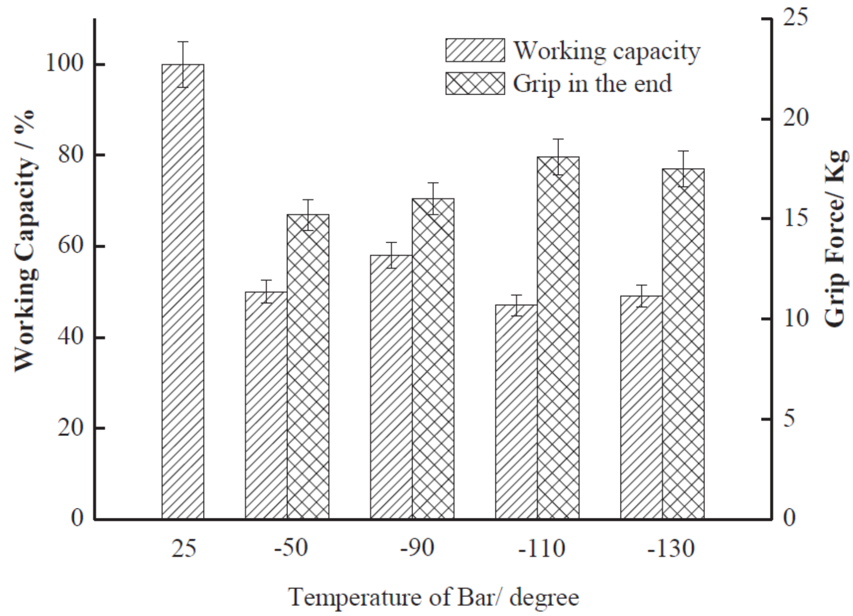

Figure 3.1 The comparison of working capacity with temperature in Treatment Group II. (Yinsheng, 2016)

Understanding how temperature and glove thickness can affect a cold storage worker by reducing productivity, decreasing dexterity and grip strength, and increasing finger fatigue assists leadership in making educated decisions on PPE selection. Finding the right glove that not only protects from the cold temperatures but has the least detrimental effects on the worker should be the primary goal.

CHAPTER 4

SELECTING THE PROPER GLOVES FOR COLD STORAGE WORKERS

4.1 Glove Selection

Choosing the correct glove for cold weather tasks can prove to be difficult; not only does the glove have to contain characteristics capable of protecting the human hand under cold conditions, but it also needs to be wearable and non-limiting for the user. Layers may be added or removed to adjust for varying temperature zones within a warehouse, but in severely cold environments or refrigerated warehouses, PPE layers are often so thick that movement becomes limited (Angelova, 2017).

In order to select gloves appropriate for cold working environments, it is important not only to know the temperature range experienced by the hands of workers, but also the type of manual work to be performed, the size, shape and the surface quality of the objects to be handled are also important. Irzmańska et. al (2018) extensively studied the cold weather glove selection problem and provided a method for selection process of glove materials for different types of cold weather work. Their study involved a two-pronged approach: (i) laboratory testing of 11 most commonly used glove materials (see Table 4.1) to determine their mechanical and thermal properties and (ii) workplace observations in order to obtain a set of objective data about manual work performed cold work environment.

Table 4.1 Characteristics of Tested Materials for Cold Protective Gloves

Symbol of material	Composition	Thickness [mm]	Type of material, weave/construction
A	60% polyamide, 40% polyurethane	0.77	Synthetic leather
B	100% polyester	1.98	Bilayer composite: - Knitted jacquard, double-knitted cast-on - Knitted plush fabric (weft-knitted)
C	84% polyester, 16% elastomer	1.62	Bilayer composite - Single jersey plated with elastomer thread
	94% polyester, 6% elastomer		- Double weft-knitted after scratch treatment
D	50% polyamide, 50% polyurethane	2.65	Weft-knitted plush fabric
E	50% polyester, 50% wool	8.46	Fur knitted fabric
F	100% polyacrylonitrile	1.90	Plated single-jersey fabric
G	External coat: 100% polyester Membrane: 100% PTFE Lining: 100% polyester	3.01	Triple-layer composite External coat: knitted fabric, Middle layer: membrane, Lining: knitted fabric
H	Polyester	6.44	Nonwoven fabric
I	50% wool, 50% polyester	3.49	Weft-knitted plush fabric
J	100% polyester	5.24	Weft-knitted plush fabric
K	100% natural leather	0.76	Lambskin

Source: Irzmańska, E., Wójcik P., Adamus, A – Włodarczyk (2018) Manual Work in Cold Environments and its Impact on Selection of Materials for Protective Gloves Based on Workplace Observations. Applied Ergonomics 68: 186-196.

Mechanical and thermal tests were performed in a glove manufacturing facility according to prescribed standards. Properties of the glove materials important for selection were: (i) abrasion resistance measured by incremental number of abrasion cycles until the material wore down (Figure 4.1); (ii) Hygienic parameters measured by degree of surface wetting (Degree = no surface wetting or hydrophobic surface to Degree 1= complete wetting of the entire surface (Figure 4.2); (iii) Insulation parameters in terms of dry thermal resistance (classes 1 and 3 were the lowest and highest values) (Figure 4.3); and (iv) Ergonomic properties measured in terms of bending stiffness in longitudinal and transverse bending moduli (Figure 4.4).

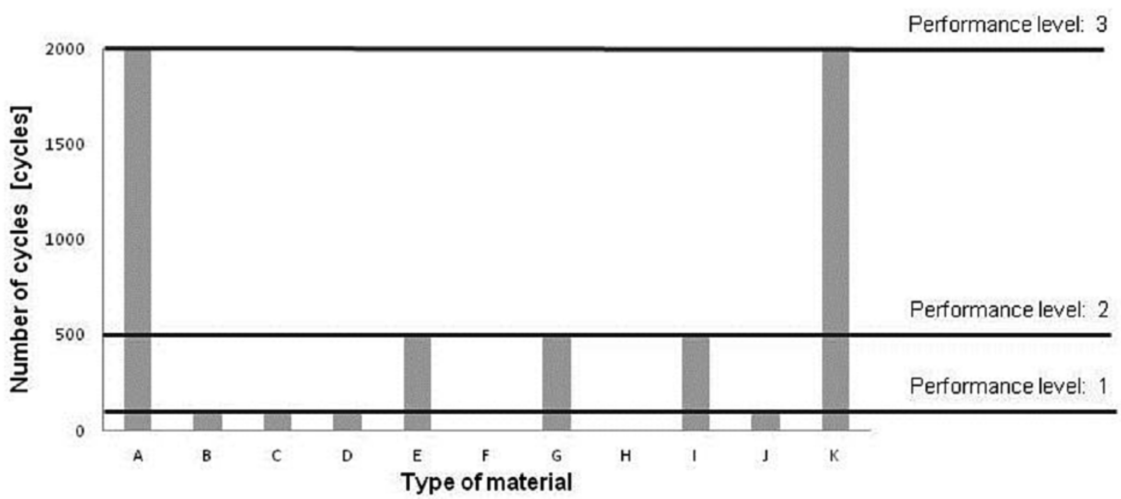

Figure 4.1 Abrasion resistance test results. (Irzmańska et. al 2018)

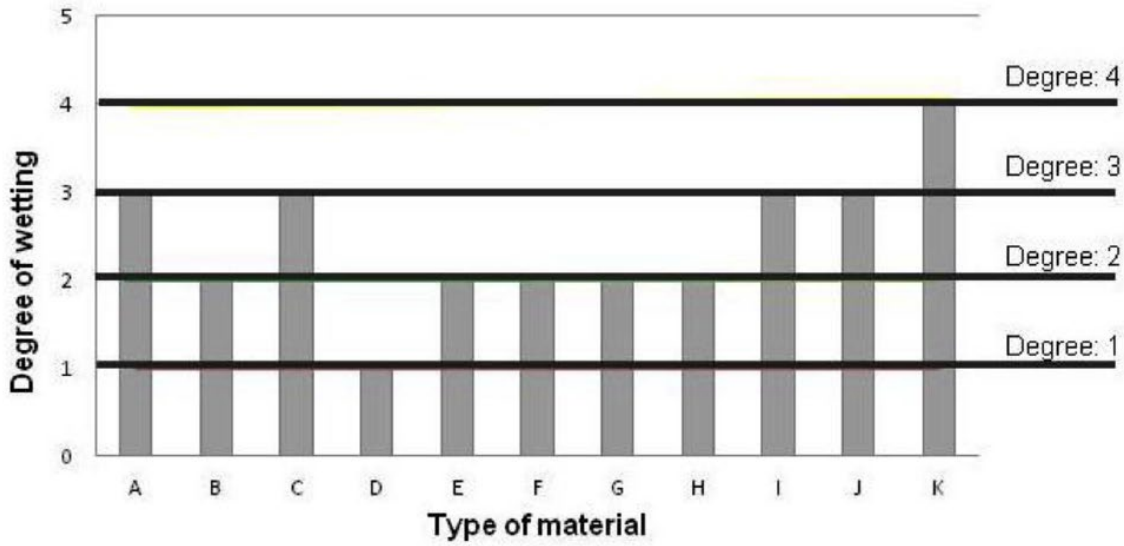

Figure 4.2 Surface wetting test results. (Irzmańska et. al 2018)

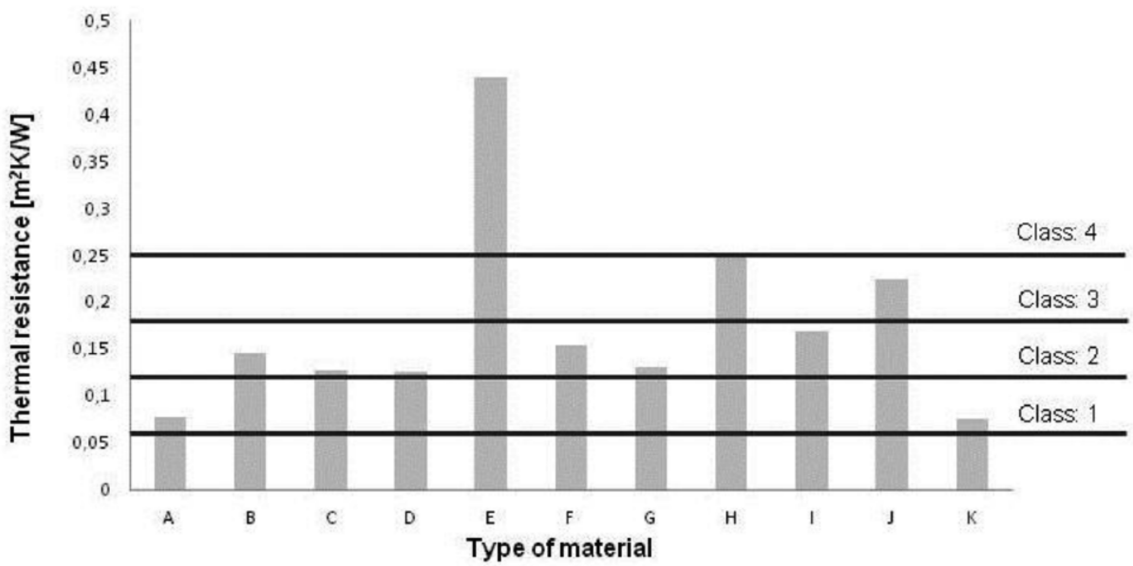

Figure 4.3 Thermal resistance test results (m2K/W). (Irzmańska et. al 2018)

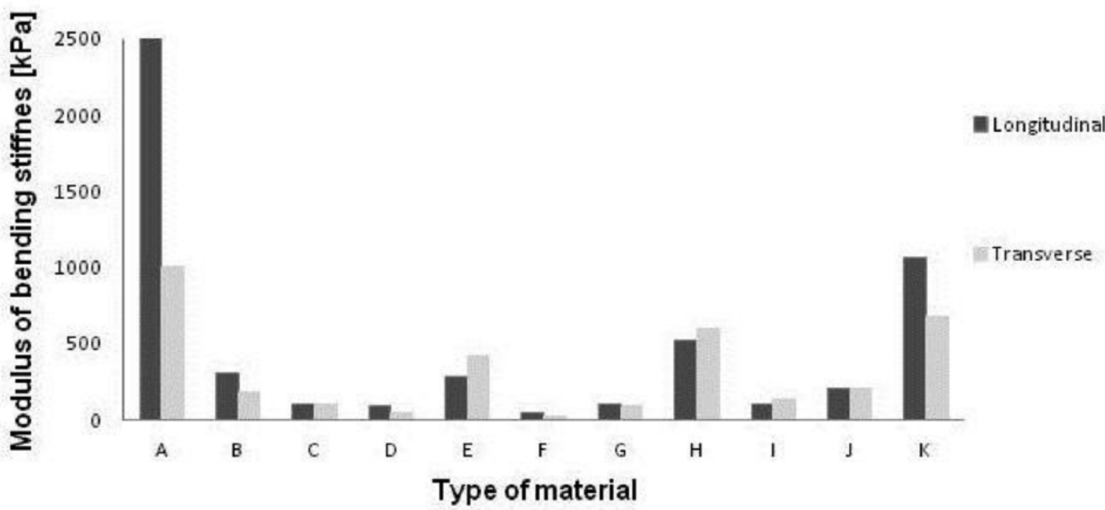

Figure 4.4 Bending stiffness test results (kPa). (Irzmańska et. al 2018)

The researchers studied 107 workers performing tasks in refrigerated environments in seven different companies. The cold environment work involved meat cutting and boning, processing meat, manual sorting of frozen products, manual product handling and loading, weighing intermediate products, multi-packaging, and product labelling. They classified work in cold environment into three major sectors: production, warehousing and packaging.

In the production sector, workers were involved in manually sorting frozen products, or worked in meat cutting and boning operations or worked in processing cold cuts. The hands of the manual sorting worker came in contact with frozen and frosted surface types (−15 °C and −10 °C, respectively). The objects were spherical (fruit) or cylindrical (vegetables) with a weight of 10 g–400 g. Other workers in the production sector were involved in meat cutting and boning came in contact with wet surfaces with a temperature of 0 °C or 6 °C. These workers handled cylindrical objects (meat pieces). Workers processing cold cuts and meat handled objects weighing 500–2000 g. Based on the work analysis, glove characteristics for production workers were recommended to be: made of materials with medium to low abrasion resistance (levels 2 and 1), medium hygienic properties (surface wetting degree 3 or 2), high to medium insulation (thermal resistance level 3 or 2) and good ergonomic properties (low bending modulus). Examples of glove materials that satisfied these requirements include a bilayer material composed of double-knitted cast-on jacquard and knitted plush fabric (B) and weft-knitted plush fabric (J) (Table 4.1).

In the warehousing sector, workers performed three types of tasks: (i) loading frozen products, (ii) manually moving loads, and (iii) handling loads. Workers in the first group experienced hand contact temperature of −10 °C or 0 °C. Object surfaces were dry or frosted and the objects were spherical in shape (sacks) and weighed 1000 – 5000 g. Workers of the second group had hand contact temperature 0 °C to 6 °C with the objects having frosted surfaces with a temperature of 0 °C to 6 °C. The objects were cubic (cardboard boxes) and weighed 5000–7000 g. The third group worked with objects with dry surfaces at a temperature of 0 °C–6 °C. The objects were cubic (crates) and weighed 5000–7000 g. The glove characteristics for warehouse workers were recommended to be: medium abrasion resistance (levels 3 and 2), good hygienic properties (surface wetting level 4, 3, or 2), medium insulation (class 2 thermal resistance), and good ergonomic properties (low bending modulus). Examples of suitable materials proposed were a triple-composite made of knitted fabrics and a membrane (G), weft-knitted plush fabric (I), and lambskin (K).

In the packaging sector, workers performing inspection and monitoring tasks had hand contact temperature with objects that were between 0 °C and 6 °C. During the weighing of products, they encountered wet, frosted surfaces. The shape of the objects were cubic containers and the weight was 1000–5000 g. Workers packaging products into multipacks and labeling products worked with slippery surfaces. The glove characteristics for this group were recommended to be: medium to low abrasion resistance (levels 3 and 2), low surface wetting resistance (surface wetting level 1), medium to low thermal insulation (level 2 or 1), and high ergonomic properties (low bending modulus). Materials selected for this type of work included weft-knitted plush fabric (D, I) and a triple-layer composite consisting of knitted fabrics and a membrane (G).

Authors provided a comprehensive study of various cold storage work that identified the major task characteristics critical in the selection of cold protective gloves. The study showed that the type of cold surface contact workers' hands underwent and the nature of manual tasks performed should be taken into account while selecting materials for protective gloves to be used in cold working environments. Authors reported cut resistance test results, tear resistance test results and puncture resistance test results for the gloves materials that could be used to improve the selection of materials when such properties are important in the cold work.

4.2 Choosing between Comfort & Functionality

OSHA requires that personal protective equipment (PPE) be used to reduce an employee's exposure to hazards when engineering and administrative controls are not adequate to reduce the hazard to a lower risk rating. As simple as this may seem, PPE also needs to be considered wearable and non-restrictive to encourage continued use by the employee. Conversations that revolve around PPE selection also need to consider how the employee with receive and use the equipment. According to a 2007 survey by the National Safety Council, eighty-seven percent of safety professionals said they have observed workers failing to wear PPE when there were clearly set standards and PPE readily available. This noncompliance stems from multiple reasons; sixty-two percent cited discomfort as the reason why they failed to follow PPE protocol, and the second reason was ease of task without the use of PPE. Additional reasons included PPE being too hot, fit poorly, unattractive looking, or not easily accessible from the site of the work task. (McPherson, 2008).

The results of a study conducted by Akbar-Khanzadeh et al. (1995) at an automobile plant revealed that only 42% of workers reported that gloves where comfortable to use while offering protection. Furthermore, workers who considered their PPE to have fit issues, inadequate functional design or reduce comfort while working, opted out from using the PPE due to overall discomfort. One of the more difficult challenges faced by employers is finding PPE that not only protects the individual from the hazard but also provides adequate comfort that would promote usage by the employees. The resistance to wearing protective equipment is one of the considerations that should be most carefully examined during the design (Dianat et al. 2014; Feeney, 1986) and selection.

Cold weather glove design has greatly improved throughout the years by integrating comfort and functionality into the design of PPE, but we still have a long way to go to achieve improved functionality and protection for tasks that require maximum dexterity in below freezing temperatures. Currently at the Amazon Fresh sites, EHS specialists are faced with the everyday dilemma of imposing strict adherence to PPE policies when entering the facilities walk-in freezer as employees consistently complain that the provided gloves do not keep them warm enough (Personal experience while working as a Safety Specialist in Amazon Fresh). This leads to an abundant violation of PPE policy as employees find alternative measures to keep their hands warm that sometimes result in frost bite injuries. At this site, the walk-in freezer is kept at -10 degrees F and the gloves provided and enforced with the PPE policy have a tested manufacture rating to be functional at -20 degrees F. However, this cold rating issued by the manufacturer is not based or enforced by government regulated testing and rating parameters, as there is no such cold protection rating for gloves or any PPE in the United States. The U.S. PPE standard for hand protection, 29 CFR 1910.138, specifies the selection criteria to be used when providing hand protection. However, unlike the other revised PPE standards for eye and face, head and foot protection, the hand protection regulation does not specify testing and rating criteria. The standard states "Employers shall base the selection of the appropriate hand protection on an evaluation of the performance characteristics of the hand protection relative to the tasks to be performed, conditions present, duration of use, and the hazards and potential hazards identified." As stated in OSHA Standard Number 1910 Subpart I Appendix B (paragraph 2) ,"It should be the responsibility of the safety officer to exercise common sense and appropriate expertise to accomplish these tasks” (Donnelly: OSHA, 1995). It is important to note, that even with standards in place for testing and rating, it is difficult to correlate glove properties assessed in a laboratory with the actual protection and comfort that can give workers (Irzmańska E et.al, 2018), as cold temperatures have varying effects on the PPE’s effectiveness based on the complexity of task, its requirements and the consumer physiological variables. In the battle between choosing function and protection over comfort concerns, function and protection is the wiser course of action.

4.3 Cold Glove Standard EN 511:2006

As previously stated, the United States has no regulated standard on glove protection in cold environments. Currently, the US has standards for impact protection and cut resistant glove protection that can be found in the American National Standards Institute (ANSI) and the International Safety Equipment Association (ISEA) standards. The ANSI Standard classifies nine levels of cut protection that indicate how many grams of cutting load a glove can withstand from a sharp blade before being penetrated (Figure 4.5). The levels range from Cut Level A1 which takes 200-499 grams to cut, up to Cut Level A9 which takes 6000+ grams to cut. This cut level is displayed in a badge that resembles a shield and printed on the exterior of cut resistant gloves. Presently, there are no standard testing or rating parameters within the United States for the production and sale of cold temperature gloves that would list a glove as legally acceptable for use in varying cold temperatures.

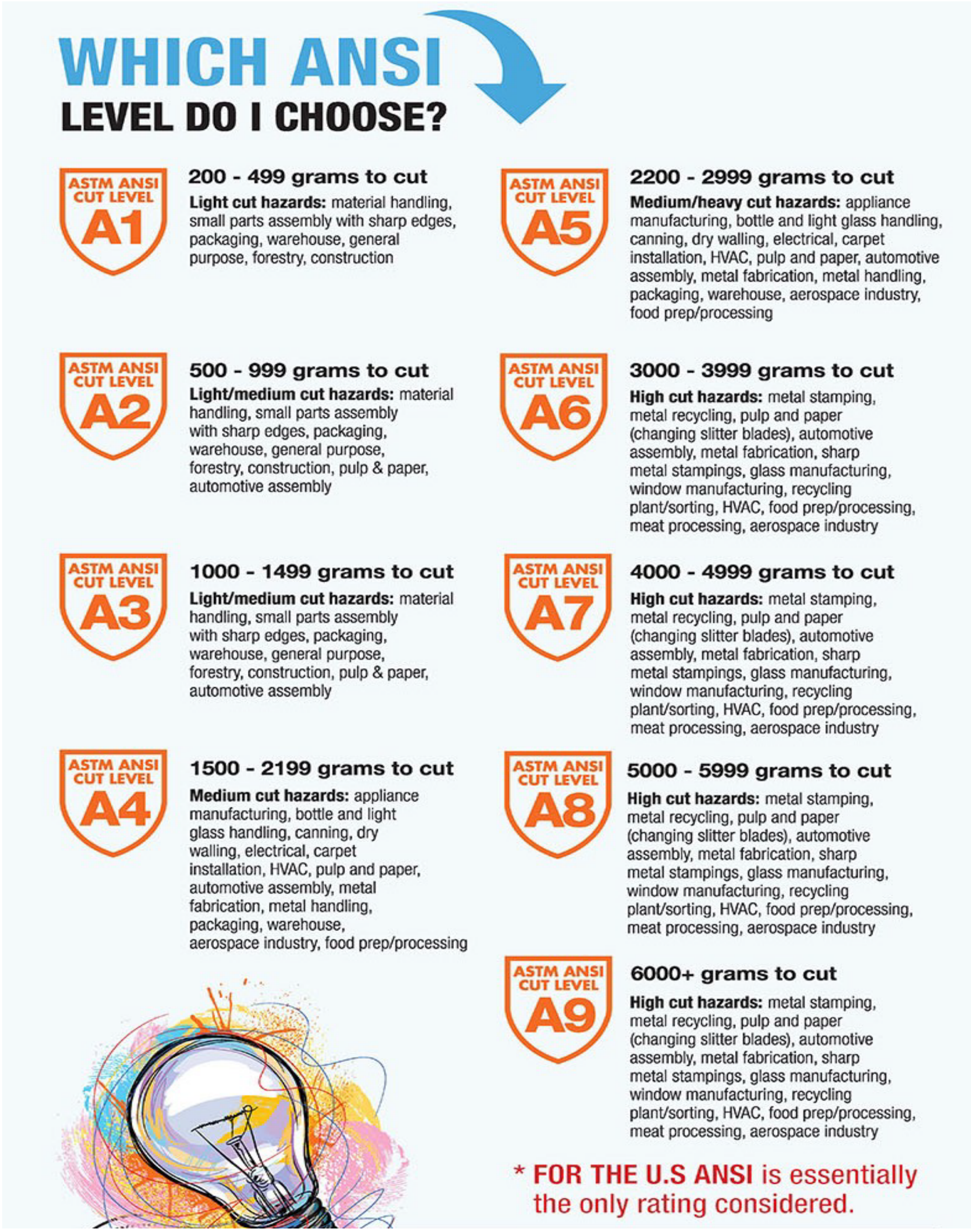

Figure 4.5 United States ANSI/ ISEA cut levels indicate how many grams of cutting load a glove can withstand before being penetrated or cut by a sharp blade.

Source: https://www.superiorglove.com/en/work-gloves-101/guide-to-ansi-en388-cut-levels

Worldwide, the main standard defining the technical requirements and test methods for gloves designed for cold protection is EN 511:2006 (Irzmańska E et.al, 2018). This is a European Standard that is used for any glove which claims protection against cold environments. The standard includes two specific tests for assessing thermal insultation from convective cold and contact cold and addresses glove concerns protecting the user from heat loss through convection and direct contact. From these tests, an insignia is completed with the resulting ratings and often stamped on the back hand of the glove (Figure 4.6). The first number under the EN511 insignia informs the user on the gloves level of protection from cold, with a number from 0-4; where 4 is best. The second number under the EN511 insignia inform the user on the gloves level of protection against contact cold with a number from 0-4; where 4 is best. The last and third number under the insignia informs the user of the gloves capability to resist water penetration; 0= water penetration after 5 minutes and 1= no water penetration after 5 minutes. In the presence of an X rather than a number, this indicates that the glove has not been submitted to the test or the test method appears not to be suitable for the glove design or material.

Figure 4.6 Glove manufacturers who have adapted the European Standard EN 511:2006 print the gloves rating on the back hand of the glove.

Although standardized testing, rating and production does not explicitly guarantee a glove would be effective in their intended work conditions, having universal standards provide a higher level of product safety and quality. Within the U.S. for hand protection, there are no specific standards in OSHA or ANSI. OSHA simply states general requirements, that employers shall select and require employees to use appropriate hand protection when employees' hands are exposed to hazards such as those from skin absorption of harmful substances; severe cuts or lacerations; severe abrasions; punctures; chemical burns; thermal burns; and harmful temperature extremes. Employers shall base the selection of the appropriate hand protection on an evaluation of the performance characteristics of the hand protection relative to the task(s) to be performed, conditions present, duration of use, and the hazards and potential hazards identified (OSHA). This brief requirement of the U.S. regulatory requirement for gloves does not offer specifics for testing, design and function of gloves. It would be an improvement if the U.S. either adopted the European Standards under OSHA law or created their own hand protection standards. This would not only increase the overall safety of gloves, but it would assist employers in finding the best choice PPE for their employees in cold weather storage especially regarding challenges faced in finding cold weather gloves that offer the dexterity needed to keep performance high and maintain steady warm. Until improvements are made, employers can use additional methods and improve worker comfort and concerns while working in these low temperature environments.

CHAPTER 5

RECOMMENDED SOLUTIONS

The importance of hand function in the cold warehouse working environment pushes professionals and researchers to find alternatives or solutions that would maintain manual performance in the cold temperatures, whether it be through protective clothing, external heating or administrative methods. Although gloves can help conserve heat and protect hands from damaging temperatures it also decreases manual performance. In very limited situations, bare-handed performance can prove to be better than gloved performance given exposure to the hands are not severe or long term (Rogers et.al. 1984). In temperatures that bare-handed performance is not feasible, glove wearing has proven to be critical for protection and safety. Although they impair performance and can cause long term musculoskeletal issues long term and prove to be uncomfortable, this has been deemed an acceptable tradeoff for employers. With gloves remaining the optimal choice of PPE, the industry still lags behind in creating a product that does not hinder productivity and provides the required cold protection without trading one for another. But while the PPE industry works toward researching and testing new products, companies can look to other methods of reducing risk via administrative controls and engineering controls.

5.1 Engineering Solutions

Manual performance can be conserved via methods that either help with the production or application of heat to the periphery through the use of external heating methods. One study by Lockhart and Kiess (1971) showed that using auxiliary heaters at a workstation is an effective way of conserving manual performance. Research on direct heating (electric heater in glove) in comparison to indirect heating (electric vest for torso), has showed that, on land, both methods are suitable for conserving manual performance during cold exposure (Ducharme et al., 1999). In this study, eight subjects were exposed twice to -25˚C air for 3 hours using a Torso Heating Test (THT) Where the torso is heated but hands with no gloves, and a Hand Heating Test (HHT) where electrically heated gloves were worn with arctic mitts and no THT worn. Finger dexterity tests were performed under both conditions. While each dexterity test was conducted, finger blood flow was measured using a 780 mm laser Doppler flowmeter probe (Ducharme et.al, 1999). Results showed that when using either heating application, there was no significant finger temperature difference between them while completing the dexterity tests. However, blood flow to the fingertips was significantly lower in the THT compared to the HHT. The direct heating method of HHT helps to maintain the temperature of the hand while the indirect heating by THT increases the bodies blood flow to the fingers and thus prevents the hand from cooling. Another observation was that THT auxiliary heating allowed the subjects fingers to maintain their finger dexterity during full cold exposure, however, when keeping the fingers comfortable with the HHT auxiliary heating, there was significant decrease in dexterity (Ducharme et.al, 1999).

Heated gloves would be best suited in tasks that require longer exposure times over 50 minutes where thermal sensation disappears in temperatures below -12˚C (Geng, 2001). They can be used during high and low frequency tasks as they not only provide the user with flexibility and comfort but also warmth and protection. Warehousing departments such as inventory, sorting, troubleshooting and shipping/receiving would be the optimal areas of usage as they typically work longer shifts within one area and least likely to directly handle food products or orders reducing risk of water saturation or condensation developing on a battery-operated glove.

The use of heated gloves may solve the issue of cooling finger temperatures within the refrigerated warehouses, but as proven by Ducharme, it comes at the cost of dexterity reduced over time. For these reasons, employers can combine both use of auxiliary heating gloves or suits, with administrative controls that would decrease the length of time spent in a restrictive cold environment.

5.2 Administrative Solutions

Time is an important variable when evaluating how temperature affects the body. The longer a worker performs within a cold environment, the risk to the body increases. Limiting worker exposure to cold working environments with time maximums can reduce the fatigue, dexterity loss and loss of finger sensitivity. Geng, 2001 suggests that a complete loss of hand comfort with gloves occurs after 50 minutes with temperatures below -12 ˚C. After evaluating a Job Safety Analysis for each task performed in cold temperature spaces, maximum time limits should be set below 50 minutes and enforced by management leadership. Because every task is different in their needs and requirements, time limitations should vary. For example, a task that requires higher finger dexterity, fine-finger movement and quick movements should spend less time in a cold temperature environment, compared to a task that requires dynamic or large movements that does not require intricate use of fine motor skills. Another suggested administrative control would be to add warm-temperature staggered work breaks in between each task in an area where the employee can warm their core and peripheral body temperatures back up to normal before heading back into the cold temperature. From personal experience the Amazon Fresh warehouses, set 10-minute warm up periods after each 50 minutes of task within the walk-in freezers set at -20 ˚C. Although these administrative controls were in effect at the site and proved effective for business productivity and met minimum company safety requirements, there were regular requests and complaints by employees that either the warm up periods were not long enough to bring sensitivity back to fingers, or overall length inside the walk in freezers was too lengthy. These concerns should be considered when creating administrative time controls for employees to prevent PPE violations and disgruntled employees.

Unfortunately, there have not been any studies conducted to date that evaluate how warm up breaks affects worker performance in cold storage warehouses and should be an avenue further explored as the industry continues to grow. It is important that until manufactures provide PPE that provides temperature protect without diminishing dexterity and creating hand fatigue, employers need to implement administrative controls that would improve hand performance and overall productivity in cold environments. Implementing administrative controls in coordination with task appropriate PPE can improve employee participation and reduce physiological effect cold temperatures and thick gloves can have on the employees' hand.

CHAPTER 6
CONCLUSIONS AND FUTURE DIRECTIONS

In order to improve the safety of those who work in cold environments, this research study has presented how working in cold environment affects human thermoregulation which in turn affects both work ability and productivity. This review has shown that there is a direct relationship with how glove thickness and temperature that can affect hand fatigue and grip strength, leading to reduced productivity in employees. Thicker gloves increase hand strain and require a greater hand force to complete tasks. This causes a gradual decline in grip strength which is further reduced if colder temperatures are introduced. Procedure for optimum selection of mechanical and thermal properties of the gloves material has been presented to improve choice of glove material according to type of cold storage work. Finally, studies on alternative solutions of local heating in gloves and torso has been discussed.

This review also highlighted that further research is needed on the effects of cold exposure on complex tasks specific to grocery picking in refrigerated warehouses and walk in freezers. Many of the experiments discussed did not take into account using additional technology such as touchscreen handheld computers, or maneuvering shopping carts and totes. The use of these items is common in e-grocery warehouses and should be evaluated directly. Also, further research needs to be conducted on the engineering of cold weather gloves. A U.S. National Standard should be created for gloves manufactures that places pressure on the companies to better performing and protective cold temperature gloves that offer the high dexterity and functionality required to complete complex tasks in these cold environments, without sacrificing comfort and warmth.

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