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An analysis of user comfort for wearable devices and their impact on logistical operations

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An analysis of user comfort for wearable devices and their impact on logistical operations

By

Eboni Noelle Smith

A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctorate of Philosophy
in Industrial and Systems Engineering
in the Bagley College of Engineering

Mississippi State, Mississippi

December 2019

An analysis of user comfort for wearable devices and their impact on logistical operations

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This dissertation is comprised of three different studies researching user perception of comfort when using wearable technology. The first study investigated the use of altered smart glasses to study comfort, preference, and performance while executing common logistical order picking and shipment putting tasks. The impact of design type (weighted front, side, or back) was investigated using comfort rating scales (CRS). There was no significant difference in device preference regardless of task type. Despite the side weighted arrangement being the most comfortable, the participants still felt uncomfortable. The second study explored modifying the weights to the six dimensions of the CRS to create a comfort score. There was a strong correlation between the weighted and unweighted comfort score. Participants identified Harm as the most important dimension. The results suggests that the participants valued importance did not make a difference in the comfort score. The final study examined the use of a wand scanner and two wearable devices to study comfort and performance while executing common logistical shipment putting tasks. The impact of the wearables was investigated using the CRS. Participants identified the ring and wand scanner to be the most comfortable and the glasses as the least comfortable device. The CRS scores showed that participants became more uncomfortable using

the smart glasses over time during the completion of the putting task. These three studies

provided insight for industry from a comfort perspective that will be helpful when trying to

incorporate wearable technology in the work place.

DEDICATION

This work is dedicated to my parents, Captain Emanuel Smith, III and Dr. Debra Walker Smith, and my aunt, Rev. Dr. Cecelia A. Walker, whose shoes I constantly strive to fill.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Wearable technology has been the focus of recent research in medicine, athletics, academia and the industry. These fixtures are used on the external parts of the body and can be an accessory or attached to an item of clothing. Wearable devices include but are not limited to watches, wristbands, rings, and glasses. The benefits of more flexibility, convenience of instant access to information and collection of data through touch or voice commands increases the desire to use this product.

With increased interest in wearables, it is important that companies also understand the risks associated with this technology before updating processes to support the use of these devices. The use of devices could impact the performance and health of the wearer by several different factors such as size, physical and distribution of weight, and the shape of the device. There is a need to understand how using these devices throughout the workday will impact the workers comfort. When wearing computer devices, comfort is referred to as musculoskeletal loadings that are applied to the body that can cause the user to feel uncomfortable (Knight et al., 2006). Users musculoskeletal systems can be impacted when wearing wearable devices depending on the adjustments that the wearer makes which could potentially put them at risk of having a work-related injury.

The Comfort Rating Scales (CRS) is a tool that has been created to assess user comfort when using wearable devices. According to Knight et al. (2002) the six factors that measure

x

comfort are emotion, attachment, harm, perceived change, movement and anxiety. Users comfort

levels rated by physical changes are accounted for with attachment (feeling the device physically

on the body), harm (damage to body), perceived change (feeling different), and movement

(affects user movement). Comfort is not only physical but also psychological. Having the

emotion (concerns with appearance) and anxiety (worrying about device, safety, and reliability)

scales accounts for mental comfort.

1.1   Dissertation Objectives

The primary objective of this research is to understand how the use of wearable devices is

impacted by comfort. Additionally, this research sought to understand how comfort impacts

productivity while completing a logistics task in an experimental environment.

CHAPTER II

COMFORT ANALYSIS OF USING SMART GLASSES DURING THE "PICKING" OR

"PUTTING TASK

2.1   Introduction

As technologies supporting augmented reality (AR) and head mounted display (HMD) or

head-worn display (HWD) devices continue to advance, opportunities grow for solutions like

"smart glasses" to be used in industrial environments. Industrial companies and workers believe

that there is a future for utilizing smart glasses for tasks such as order picking, inventory counts,

quality control, maintenance and repair, training and education, and remote collaboration

(Glockner et al., 2014; Kim, Nussbaum, & Gabbard, 2016). Presently, there are numerous

vendors, such as Google™ and Vuzix®, creating smart glasses, yet very few industrial

organizations have adopted them into their work processes and tasks. How the products are

marketed and the differences amongst the products' design, technology, and functionality make

deciding which brand to invest in, is challenging. As a result, research has been conducted to

review available smart glasses, and aid in the selection process for companies choosing which

product they would like to implement. This AR selection validation research focuses on the

comparison between Atheer AIR™ Glass, Epson Moverio™ BT-200, BT-300 & BT-2000,

Laster wave™, Optinvent™ ORA-2, ODG™ R-7, Penny® C Wear Extended, Racon Jet™,

Sime™ G3, SmartEyeglass™, and Vuzix® M100. These products were evaluated based on 18

defined parameters: price, powering, weight, field of view, battery life, optics, camera, open API,

audio, sensors, controls, processors, storage, memory, connectivity, operating system, and ingress protection against dust and water. This research concluded that the Epson-Moverio™ BT-300 would be the best choice, but also acknowledged the fast pace of growing technology and the possibility of a better product appearing to the market soon. (Syberfeldt, Danielsson, & Gustavsson, 2017).

While there is an abundance of AR solutions for industrial companies to select from, there is a lack of research from the point of view of user comfort when wearing smart glasses for long shift durations. The weight of a normal pair of glasses is about 20 grams (Syberfeldt et al., 2017). Syberfeldt et al. (2017) recommends that the weight of the glasses not exceed 100 grams. Glasses weighing over 100 grams could cause the user to experience too much physical strain. Currently, Vuzix® M100, Penny® C Wear Extended, Epson Moverio™ BT-200, and SmartEyeglasses™ weigh the lightest at 70 grams, but are still much heavier than a normal pair of glasses (Syberfeldt et al., 2017). As a result, AR device users could experience discomfort from the hardware if worn for a long period of time (Stoltz et al., 2017).

Given the challenges that the weight of AR glasses pose and the minimal amount of research investigating comfort for wearing smart glasses over long periods of time, the purpose of this research study is to provide companies with recommendations regarding how to modify smart glasses while not altering the comfort for the workers. For this reason, comfort level while performing two industrial tasks—order picking and package putting— is evaluated while wearing pairs of modified smart glasses that had additional weight added to the front, side, or back. This study provides an understanding of how and where to alter smart glass technology by adding needed components (e.g. memory, storage, battery, sensors, imagers, expansion units

such as microUSB, etc.) to the frame of the glasses while ensuring the device remains comfortable.

2.2   Literature Review

AR is considered to be a potential tool for aiding in logistics' and operations management's four main warehousing tasks: receiving, storing, picking, and shipping (Cirulis & Ginters, 2013). The warehousing task receiving includes unloading materials from a transportation carrier, completing an inspection and updating the inventory. The products are then transferred and placed in a storage location (De Koster, Le-Duc, & Roodbergen, 2007). Order picking is when items are gathered following a customer's order (Reif, Günthner, Schwerdtfeger, & Klinker, 2009). Once the orders are filled the packages are ready to be taken to their designated locations for shipping. For this study, the term putting relates to the tasks of the workers receiving, storing, and shipping the items (***Figure 2.1***).
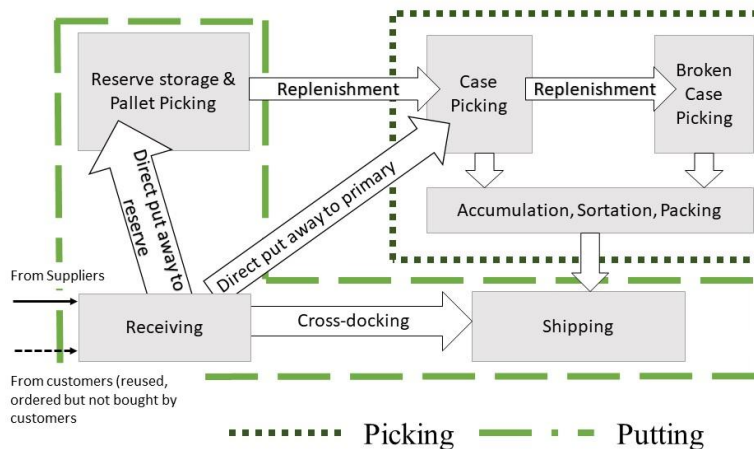
Figure 2.1   Defining Picking and Putting Task

Paths products can take in a warehouse (De Koster et al., 2007) updated to identify process areas associated with picking and putting.

Currently, there is a void in research on putting task operations due to having a small influence in deriving costs for the warehouse in comparison to other companies (Davarzani, & Norrman, 2015) and logistics workers in this department typically only need a high school diploma (Cirulis, & Ginters, 2013) which allows the company to pay these workers minimum wage. With low wages, corporate mentality may be to simply "throw more workers" at a problem as opposed to making significant investments into new technology solutions thereby reducing the motivation to investigate solutions with equipment costs. These low wages could also have a negative impact on the companies by causing logistics positions to remain understaffed. When other companies with material handling jobs offer higher wages, shift workers may leave for more money leaving bottle-neck position understaffed causing the focus to be on finding employees and taking focus off of advanced technology solutions such as AR. Regardless of reasoning for limited research, applications of AR for putting tasks such as receiving, storing, and shipping tasks are believed to have the same benefits as those identified for picking tasks (Stoltz et al., 2017). See *Table 2.1* for a list of benefits.

Most order picking is still performed manually due to the complexities and costs associated with automated or robotic solutions (Weaver, et al., 2010). Picking tasks account for more than 50% of warehousing costs (Stoltz et al., 2017) and is the most labor-intensive job (Davarzani, & Norrman, 2015). Solutions that aid task guidance for the workers have evolved over recent years from the "low-tech" of paper lists to more advanced technology options such as computer handhelds with barcode scanners and imagers, to pick-by-voice and pick-by-light solutions, to the most recent opportunity which is to use AR and/or HMD (Weaver et al., 2010). Presently, order picking is the most researched topic for warehouse operations and studies have begun to focus on how smart glasses can be beneficially integrated into this task. Boeing has

been an industrial leader in pushing this technology forward (Fite-Georgel, 2011) with their implementation of Google™ Glass to aid in the creation of wiring harnesses (Kim et. al, 2016). DHL also completed a pilot study using Google™ Glass and Vuzix® to help with order picking at the warehouse and had an improvement of 25% in efficiency (Kim et al., 2016).

Vuzix® is one of the leading suppliers of Smart Glasses, AR and VR technology and other products for customers and enterprise markets. Vuzix® solutions have been distributed to customers like John Deere, WS Kunststodd-Service, Penny Market, DHL, Daimler and BMW (Newswire, 2017b). In 2016, DHL had an increase in efficiency of 25% using Vuzix® M100 in their pilot programs. As a result, Vuzix® glasses were also distributed to various industries such as technology, retail, consumer and automotive industries to be piloted (Newswire, 2016). In 2017, DHL made smart glasses the new standard for supply chain logistics to expand its "Vision Picking" solutions (Newswire, 2017a). For these reasons, it was decided to use this smart glasses device for this study.

Common challenges have also been discovered through experiments that place smart glasses and other HMDs into industrial environments. Some of the more common complaints relate to eye strain (Baumann, Starner, & Zschaler, 2012; Kim et al., 2016), eye discomfort and visual fatigue (Hoffman et al., 2008), headache, nausea, dizziness (Kim et al., 2016), and inattentional blindness (Krupenia, & Sanderson, 2006; Liu et al., 2009). Stoltz et al. (2017) also defined some barriers found while completing a study for using AR in warehouse operation (*Table 2.2*). Gaps have been identified in understanding both visual and physical comfort as well as hygiene (Kim et al., 2016; Knight & Baber, 2005). Workers with industrial jobs concerns with AR HWD technologies focus on the maturity of the device, getting their ROI, and safety and health concerns (Kim et al., 2016). Just as with putting tasks, currently there has been minimal

work done to evaluate comfort in order picking situations. The unbalanced weight on the glasses

can lead to discomfort if worn for long periods of time (Brusie et al., 2015).

Table 2.1   Advantages of using AR in industrial operations (Stoltz et al., 2017).

Advantages	Rationalization
Reduced Error Rate	Memorization of actions to complete is not required
	An image of the product can be found in the field of view.
	Decision making is limited.
	Easy to double check
	Steps are not impacted by operator
More flexibility	Offers a hands-free solution.
	Flexibility for displaying information.
	Simpler process to check on operator
	Device proposes central field of view option.
Improved reliability	Opportunity to share media information of a defeat or issue with a manager not on site.
	Instructions are easily provided to operator limiting memory lapse.
Increased speed	Decreases the error rate.
	Limits travelling to access fixed computers, carry a scanner, etc.
	Helps anticipate the moves and result in faster movements.
Adaptability	Does not need a specific environment.
	Suitable for people with disabilities.
Safety	Hands-free device can be safer for a human operator.
	Can provide feedback and information for safety purposes or warn of immediate danger.
New technology	Brings enthusiasm to operators.
	Shows that the company adapts itself to latest innovations.

Table 2.2   Disadvantages of using AR in industrial operations (Stoltz et al., 2017).

Disadvantages	Rationalization
Hardware Limitations	Commercial scanners and smartphone cameras provide faster and more reliable solution for scanning barcodes and QR codes.
	The battery is not designed to last for long hours in order to cover a full working day.
	Processors overheating and slowing down after long periods of use or when complex computing is required can affect the physical process.
	Many wearable devices available are not designed for long period of continuous use which can cause comfort problems
	Using head-mounted devices, certain operations can be very slow compared to hand-held devices (e.g. checking multiple incoming items).
Software challenges	Programming environment/languages are not standardized.
	With user interfaces needs to be simple and have intuitive ways to interact with the devices to avoid confusion.
	Screens might not automatically adapt to change of light.
Acceptance	Privacy issues limit the amount of time users are willing to wear a device with camera and mic.
	Potential confidentiality issues because AR devices can capture photos or videos
Cost	The total cost of ownership is still quite high especially if wearable devices are considered to be personal equipment.
	Alternatives IT solutions for warehouse management can be significantly cheaper and with established benefits.
	Internal IT teams cannot easily maintain and extend AR solutions thus causing extra costs.

The objective of this research was to investigate how weight modifications to the Vuzix® M100 smart glasses impact the end user while executing a picking or putting task and to propose design recommendation that improve comfort and usability of the device. This objective will be explored by determining the effect of weight distribution of smart glasses on end user comfort, performance, and perception of the device. There were three types of weighted configurations that were investigated: front, side, and back. Two hypotheses were created to explain the expected findings of weight placement versus comfort, performance, and preference. It was hypothesized that the highest level of comfort will come from glasses weighted in the front. The

bridge of the nose will be able to support more of the weight. Weight added to the side and back might cause more tension to the temporal portion of the head. It was also hypothesized that higher ratings in performance and device preference will come from glasses weighted on the side. This weight placement may cause the glasses to move less.

In order to measure comfort, the comfort rating scales (CRS) which is a tool designed specifically for assessing the comfort of wearable computers and devices (Knight et al., 2002), was used for this study. The scales identified for this tool as defined by Knight et al. (2002) are: Emotion, Attachment, Harm, Perceived Change, Movement, and Anxiety. The researchers who designed the CRS believed that multiple scales should be used for targeting the experiences and specific parts of the device that could cause the user to experience discomfort (Knight, et al., 2002).

This study also investigated the differences in end user comfort, performance, and device preference between picking and putting tasks while wearing smart glasses. The three weighted configurations of the glasses will remain constant between task types but will counterbalanced between participants. A third hypothesis was created to predict outcomes between the picking and putting task types. There will be no difference in device preference regardless of task type.

Lastly, this study evaluated the end user performance and preference for weighted configurations based on head shape, height, gender, and other physical attributes that may impact how the smart glasses fit during task completion. It was hypothesized that the device configuration preference will be impacted by head dimensions and height (increased head movement during task).

2.3   Methods

To complete this study a team was created that included an academic advisor, principal investigator, and three undergraduate researchers. The team met a few times to brain storm how the procedures for the study should run and used that time to develop the picking and putting stations in the Human Factors and Ergonomics lab. This section will cover the materials needed, how the participants were recruited, and the steps for completing this study. This experiment is designed for the picking and putting processes used in warehousing and was run in a lab setting.

2.3.1   Materials

This study utilized three pairs of Vuzix$^®$ M100 glasses and a Polar$_®$ wearable chest band. The Vuzix$^®$ M100 glasses were used to complete the comfort research. The Polar$_®$ wearable chest band was used to keep track of the participants' heart rate during the study (***Figure 2.2***).

Figure 2.2   Polar Wearable Chest Strap

A one-ounce weight was added using fishing line to each pair of glasses in one of three locations: (a) the front of the glasses frames, (b) the right side of the Vuzix$^®$ attachment piece, and (c) the back-right side of the glasses frame above the ear piece (***Figure 2.3***). Other materials used in this study were calipers for measuring head dimensions, a tape measure for recording wingspan (armlength) and head circumference, a stop watch for keeping trial length consistent,

and wall chargers to ensure all three pairs of Vuzix® glasses were properly charged between

trials.
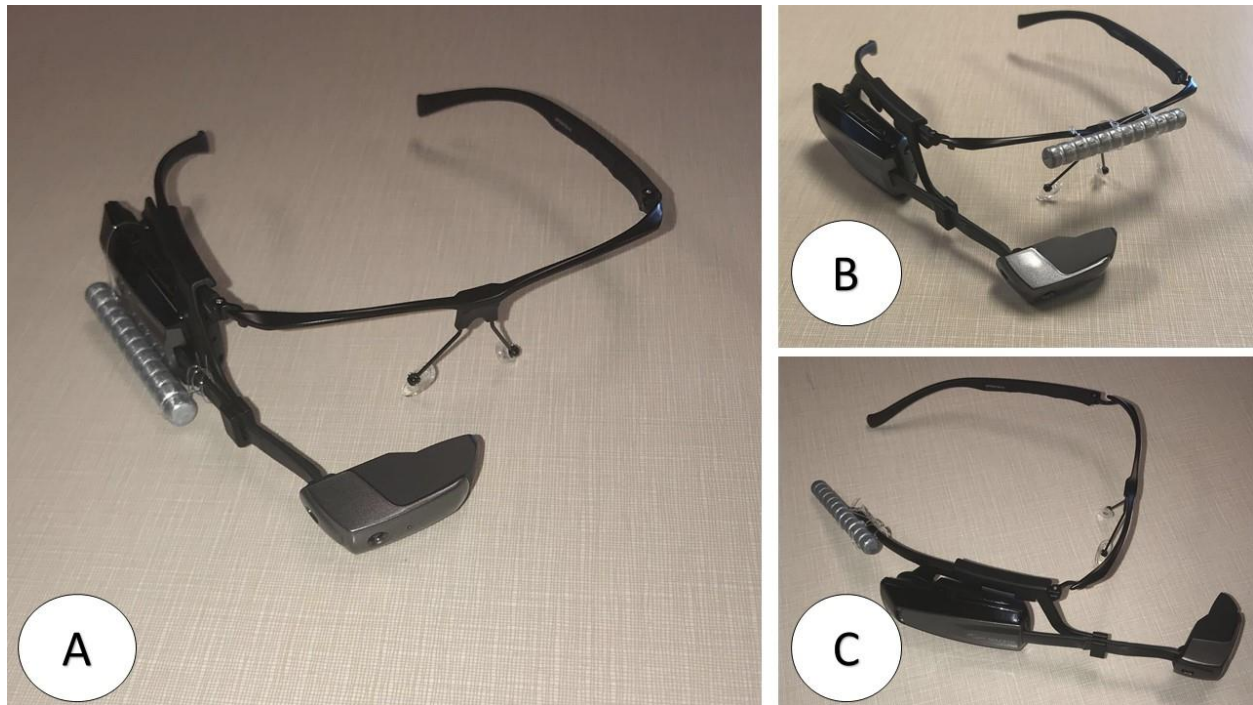
Figure 2.3   Weighted Smart Glasses Configurations

Weight modification positions for the Vuzix® smart glasses used in this study: 3a) weighted side,
3b) weighted front, and 3c) weighted back. Each weight for each of the three configurations was
exactly one ounce.

2.3.2   Participants

Forty-eight participants (29 Females, 19 Males) were recruited at Mississippi State

University and Starkville, MS area. The participants average age was 22.1 (± 2.9) and average

height of 170.18 (± 4.1) cm. The study was conducted in the Human Factors and Ergonomics

Laboratory in the Industrial and Systems Engineering Department at Mississippi State

University. All participants asked to take part in routine picking and putting tasks were given the

opportunity to review the Institutional Review Board (IRB) approved recruiting material and had

to provide their consent prior to beginning the study. All participants who completed the study were compensated twenty dollars for their time. Approximately 44% of the participants were not familiar with material handling tasks such as picking and putting. Also, approximately 67% of the participants were not familiar with smart glasses and wearable heads up displays (***Figure 2. 4***).
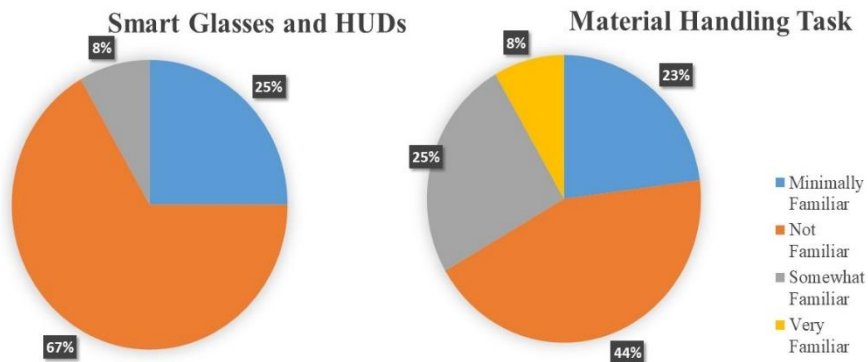
Figure 2.4   Participant Familiarity with Material Handling and Smart Glasses

Reponses from participants regarding their familiarity with material handling tasks and smart glasses.

2.3.3   Protocol

The participants were provided with details of the study to which they were selected to complete to make an informed decision and give consent. An experimenter was available to answer any questions from the participants prior to giving consent and at any other point during the study. An experimenter completed the demographic portion of the survey by asking the participants the questions to record data such as age, height, vision needs, and their experience with the items discussed in ***Figure 2.4***. Two undergraduate researchers were available during each session to assist with taking measurements of the head width, length and circumference, as

well as the wingspan of the participants. Participants were then asked to go to the restroom to put

on a Polar® wearable chest band that was used to collect heart data. The participants were

instructed to place the Polar® device underneath their chest and above their abdomen while

ensuring the elastic band was tight and would not slip over the course of the trial. While the

participants were in the restroom putting on the chest band, a Vuzix® M100 smart glasses unit

was turned on and placed in camera mode (*Figure 2.5*). Since the goal of this study was to focus

on comfort, a custom AR application was not created for use in this study. However, with

camera mode showing the wearer a view of the environment through the small display screen, a

simulated AR experience was provided. A smart glasses user completing a task with the aid of

AR would look through the display to get additional information about the work being

performed. While no additional data was provided on the display for this study, the participants

had the display positioned over their right eye and they were instructed to look through the

display as they completed the task thus simulating AR usage.

Figure 2.5   Smart Glasses turned on Camera Mode

Shows the glasses set to camera mode so that the participants can look through the display, see their stations, and simulate AR usage. The camera lens is highlighted with a red square.

Upon completion of the survey, placement of the Polar® wearable, and explanations about how to wear and utilize the Vuzix® device, participants were instructed to put on a pair of Vuzix® M100 smart glasses that had not been modified (e.g. one ounce of weight had not been added). Once the non-modified device was in place, the participants were shown either the setup of the picking station or the putting station (depending on the task for which they were randomly selected). This began the three-minute familiarity session for task instruction and expectations. The participants were given the opportunity to perform the task and ask any questions or raise any concerns about the process. This trial task allowed the experimenters to provide live real-time to the participants regarding how to use proper form ensuring that all participants would perform both picking and putting operations in a consistent manner. The picking and putting stations are shown in *Figure 2.6*. A timer was used to monitor the time for the three-minute introductory period and the three 20-minute trials.

13

Figure 2.6   Staging of the Picking and Putting Task

Shows the glasses set to camera mode so that the participants can look through the display, see their stations, and simulate AR usage. The camera lens is highlighted with a red square.

2.3.3.1   Picking Task

Two sets of shelves were configured with different sized containers used to store a range of items for the participants to pick. Each set of shelving, each shelf, and each pick bin were labeled. Picking bins included items of different, shapes, sizes, and textures and included products such as crayons, markers, rubber bands, ping pong balls, bouncy balls, tape measures, stickers, weights and more as seen in *Figure 2.7*. There were 120 pick lists created that were randomly rotated through for each participant during this study. Each pick list consisted of approximately 15 items for the participant to select from the bins. There were a total of 46 bins used for this study that were spaced out amongst two shelves. The list instructed the participant

where to find the item on the shelves (shelving set, individual shelf, and pick bin), what the item was, and how many of the item to pick.

Figure 2.7   Items Setup for Picking Task

Pick list items organized in bins on two sets of shelves separated by the letters A and B.

Twenty-four participants (16 Female, 8 Male) completed the picking portion of this study (*Figure 2.8*). Participants were given a grocery bag with a pick list inside by an experimenter and were instructed to walk over to the two sets of shelving to pick the items from the appropriate bins and place the picked items inside the bag. Upon completion of the pick list, the participant would bring back the bag with the items and retrieve a new bag and list. The experimenters would check the bags and mark if they contained the correct type and number of items. If the bag contained incorrect items or the incorrect number of items, the researcher would note which item(s) had been incorrectly picked.

15

Figure 2.8   Demonstration of Picking Task

A visual representation of some of the key components of the process flow the participants went through in order to complete the picking task demonstrated by a researcher: 8a) Receiving list and bag from the table. 8b) Returning the bag once finished with pick list. 8c) Captured moment adjusting glasses while reviewing the pick list. 8d) Selecting a roll of packing tape from a lower bin to put in the bag.

2.3.3.2   Putting Task

An AMJ-style container built to specific freight truck and aircraft cargo dimensions was used to complete this portion of the study. For this study, 270 empty boxes varying in six different sizes were used (**Table 2.3**). The container was staged so that half of it was filled with the boxes stacked to the top of the container (**Figure 2.6**).

Table 2.3   Inventory of the Six Standard Size Boxes Used

Box Dimensions	Total of Boxes
20 x 20 x 16	15
10 x 10 x 10	101
8 x 8 x 8	47
18 x 12 x 12	72
6 x 6 x 20	25
26 x 6 x 20	10

List of the six dimensions of boxes and total used for each.

Twenty-four participants (13 Females, 11 Males) completed the putting portion of the study. The participants were asked to pick up between one and three boxes and then to stack them neatly, tightly, and as high as possible on the empty side of the container. An experimenter would hand the participants boxes based on a randomized list of 500 numbers created as a control in Microsoft Excel. Once the participant placed the boxes, they were instructed to bring the same number of boxes back from the loaded side of the container to the other the experimenter working on the other half of the table (*Figure 2.9*). If the experimenter noticed that the participant was bringing the wrong number of boxes back, they would be corrected.
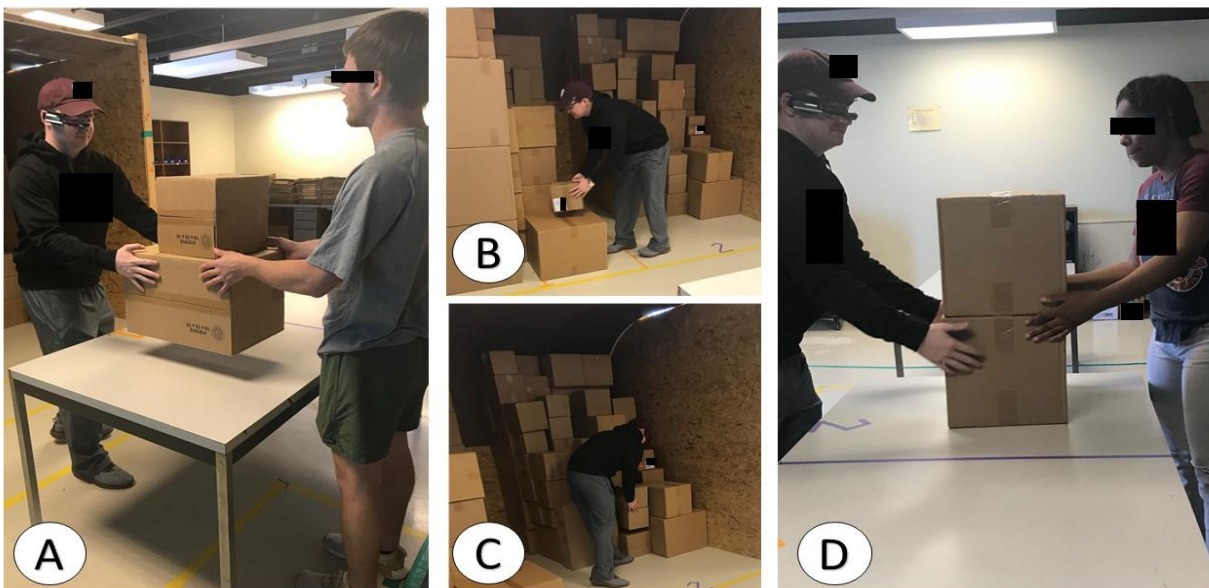
Figure 2.9   Demonstration of Putting Task

A visual representation of the participants completing the putting task demonstrated by the researchers: 1) Receives the boxes from an experimenter at the slide staging area. 2) Boxes are placed on one side of the container (the side that was originally empty). 3) Retrieves the same number of boxes from the other side of the container (the side that was originally full). 4) The boxes are returned to another experimenter on the other side of the slide staging area.

2.3.4 Procedure

The experiment began with the participant performing the manual task (either picking or putting) for three intervals of 20 minutes. During each task interval, the participant was given a pair of the weighted smart glass configurations. In order to eliminate an order effect, the order that the participants wore the different glasses configurations during the three trials were rotated in six different orders (*Table 4*). The order of the devices given to the participants was controlled in an alternated way for counter balancing.

Table 2.4   Rotation of Glasses

Rotation	1	2	3	4	5	6
Session 1	Front	Front	Side	Side	Back	Back
Session 2	Side	Back	Front	Back	Front	Side
Session 3	Back	Side	Back	Front	Side	Front

Rotation options for the weighted smart glasses.

While completing the tasks, an experimenter observed the participants and kept a count of how many times the participant adjusted their glasses. Adjustments were considered any time the participant readjusted their glasses on their face with their hand or if the glasses fell off. At the end of each of the three 20-minute sessions, the participants were asked to complete the CRS and provide statements based on previous comfort-based assessments of wearables. At the conclusion of the third 20-minute task assignment, the participants were given a final survey to rate their experience with all three smart glass weighted configurations.

2.3.5 Statistical Analysis

The aim of the analysis was to compare the CRS scores, productivity, and average heart rate by glasses type and the picking and putting task. Each dimension of the CRS was reported separately and as a total average score. Data was described using means and standard deviations.

18

In the case of repeated-measures analysis, the main and interaction effects were found for average heart rate, productivity, the amount of adjustments made to the glasses, total CRS scores and the six CRS dimensions. This analysis looked to see if any of these variables were impacted by the type of glasses, task, gender or rotation of the glasses. All analyses were performed using SPSS.

2.4   Results

2.4.1   By Glasses Type

Results from the statistical analysis are presented. ***Table 2.5*** reports a descriptive summary for the CRS, average heart rate, average adjustments made to the different weighted glasses (touches), and productivity by glasses type. To compare the productivity between the tasks the number of list completed was multiplied by 15 items on each list to get a total number of items picked.

Table 2.5   Reports Descriptive Summaries by Glasses Type

	Front Weighted	Side Weighted	Back Weighted
Emotion	4.67(5.150)	4.27(5.102)	4.92(5.255)
Attachment	14.29(4.985)	14.23(5.283)	13.46(6.773)
Harm	5.38(6.160)	4.73(5.823)	7.65(7.036)
Perceived Change	8.79(6.010)	9.08(5.896)	8.88(6.584)
Movement	9.13(6.762)	8.10(6.193)	8.15(6.517)
Anxiety	5.42(5.738)	4.83(5.755)	5.90(5.806)
CRS total	47.67(23.614)	45.25(23.469)	48.94(27.175)
Avg Heart Rate	103.405(17.455)	102.949(14.714)	103.074(15.796)
Touches	19.88(16.877)	19.27(19.289)	14.56(16.054)
Productivity	253.31(65.758)	254.313(63.215)	249.375(66.878)

Reports descriptive summaries for the dependent variables by glasses type.

For each participant trial, the amount of pick lists completed both correctly and incorrectly was recorded (***Table 2.6***). Participants completed an average of approximately 16 pick lists correctly and approximately three pick lists incorrectly.

Table 2.6   Pick List Results

Front

	Mean	Minimum	Maximum	Std Dev
Correct	16.375	9	28	4.771
Incorrect	3.0417	0	8	2.116

Side

	Mean	Minimum	Maximum	Std Dev
Correct	16.958	10	25	4.611
Incorrect	3.292	0	9	2.010

Back

	Mean	Minimum	Maximum	Std Dev
Correct	16.000	5	24	4.956
Incorrect	2.583	0	8	1.932

Descriptive statistics for the number of pick lists completed while wearing the different versions of the weighted smart glasses. (N = 24 * denotes significance at $p < 0.05$)

A record of the number of boxes moved taken during the putting trials was inserted into Microsoft Excel to calculate the number of boxes moved for each participant. The results were then copied over to SPSS and used to report the descriptive statistics of the number of boxes moved for each weighted smart glasses scenario (***Table 2.7***).

Table 2.7   Number of Boxes Moved

Front

	Mean	Minimum	Maximum	Std Deviation
Moved	261.00	160	380	59.922

Side

	Mean	Minimum	Maximum	Std Deviation
Moved	254.25	158	368	58.161

Back

	Mean	Minimum	Maximum	Std Deviation
Moved	258.75	164	394	59.141

Descriptive statistics of the number of boxes during the twenty-minute trials. (N = 24 * denotes significance at $p < 0.05$)

2.4.2   By Task Type

The results from the statistical analysis are presented. The descriptive statistics for the participants CRS scores recorded after wearing the three weighted smart glasses and completing the picking task and putting tasks are reported in ***Table 2.8***.

Table 2.8   Descriptive Statistics by Task Type

Measure	Picking			Putting		
	Front Weighted	Side Weighted	Rear Weighted	Front Weighted	Side Weighted	Rear Weighted
Emotion	6.54 (6.029)	5.04 (5.790)	6.00 (6.007)	2.79(3.243)	3.50(4.294)	3.83(4.229)
Attachment	14.63(5.428)	14.71(4.582)	14.50(4.582)	13.96(4.592)	13.75(5.965)	12.42(7.413)
Harm	6.96(7.439)	5.88(6.759)	9.58 (7.192)	3.79(4.118)	3.58(4.568)	5.71(6.450)
Perceived Change	8.67(6.041)	9.96(5.607)	10.58(6.587)	8.92(6.107)	8.21(6.164)	7.17(6.253)
Movement	10.08(6.698)	7.63(6.099)	9.63(6.755)	8.17(6.831)	8.58(6.379)	6.67(6.048)
Anxiety	5.92(6.338)	5.75(6.367)	7.54(6.129)	4.92(5.158)	3.92(5.038)	4.25(5.067)
CRS total	52.79(24.888)	48.96(23.974)	57.83(26.855)	42.54(21.571)	41.54(22.849)	40.04(24.955)
Avg Heart Rate	99.23(12.515)	99.89(11.040)	99.32(10.627)	107.57(20.729)	106.01(17.349)	106.83(19.172)
Touches	22.13(17.102)	21.75(22.806)	18.33(20.010)	17.63(16.704)	16.79(15.079)	10.79(9.829)

Reported descriptive statistics by task type.

2.4.3   ANOVA

Average Heart Rate: There was no significant main effect for glasses type (F = 0.370, p = 0.548), gender (F = 2.069, $p = 0.163$), and rotation (F = 1.081, $p = 0.395$). There was a

significant main effect for task (F = 6.148, p = 0.020), with the picking task having a

significantly lower average heart rate (M = 95.914) than those that completed the putting task (M = 109.648). There was no significant two-way interaction between the glasses type and task (F = 0.921, p =0.347), task and rotation (F = 1.334, p =0.283), glasses type and gender (F = 1.384, p = 0.250), rotation and gender (F = 0.988, p = 0.445), and gender and task (F = 0.575, p = 0.455). There was a significant interaction between glasses type and the rotation (F = 4.639, p = 0.002). There was no significant three or four-way interaction between any of these variables (p > 0.05).

Productivity: There was no significant main effect for glasses type (F = 0.016, p = 0.900), rotation (F = 1.861, p = 0.137), task (F = 1.756, p = 0.197) and gender (F = 1.357, p = 0.255). There was no significant two-way interaction between glasses type and rotation (F = 2.370, p = 0.068), glasses type and gender (F = 0.773, p = 0.388), rotation and gender (F = 2.125, p = 0.096), rotation and task (F = 0.452, p = 0.808), gender and task (F = 1.175, p = 0.289), and glasses type and task (f = 0.402, p = 0.532). There was no significant three or four-way interaction between any of these variables (p > 0.05).

Touches: There was no significant main effect for glasses type (F = 1.795, p = 0.192), rotation (F = 0.675, p = 0.646), task (F = 3.003, p = 0.095) and gender (F = 0.631, p = 0.435). There was no significant two-way interaction between glasses type and rotation (F = 1.274, p = 0.306), glasses type and gender (F = 0.985, p = 0.330), rotation and gender (F = 1.492, p = 0.228), rotation and task (F = 2.024, p = 0.110), gender and task (F = 1.960, p = 0.174), and glasses type and task (F = 1.409, p = 0.875). There was no significant three or four-way interaction between any of these variables (p > 0.05).

Total CRS Scores: There was no significant main effect for glasses type (F = 0.018, p = 0.895), rotation (F = 0.750, p = 0.594), task (F = 2.759, p = 0.109) and gender (F = 0.010, p =

0.920). There was no significant two-way interaction between glasses type and rotation (F = 0.833, p = 0.538), glasses type and gender (F = 0.862, p = 0.362), rotation and task (F = 2.158, p = 0.091), gender and task (F = 0.575, p = 0.455), and glasses type and task (F = 0.229, p = 0.636). There was a significant interaction between rotation and gender (F = 2.770, p = 0.040), There was no significant three or four-way interaction between any of these variables ($p > 0.05$).

Emotion: There was no significant main effect for glasses type (F = 0.165, p = 0.688), rotation (F = 2.076, p = 0.102), and gender (F = 0.729, p = 0.401). There was a significance between task (F = 6.823, p = 0.015), the putting task had a lower Emotion score (M = 2.843) than picking task (M = 6.074). There was no significant two-way interaction between glasses type and rotation (F = 1.384, p = 0.264), glasses type and gender (F = 1.628, p = 0.585), rotation and task (F = 1.140, p = 0.365), gender and task (F = 0.000, p = 0.988), glasses type and task (F = 2.056, p = 0.164), and rotation and gender (F = 1.960, p = 0.120). There was no significant three or four-way interaction between any of these variables ($p > 0.05$).

Attachment: There was no significant main effect for glasses type (F = 0.413, p = 0.526), rotation (F = 0.987, p = 0.445), gender (F = 0.074, p = 0.788) and task (F = 0.500, p = 0.486). There was no significant two-way interaction between glasses type and rotation (F = 0.235, p = 0.943), glasses type and gender (F = 0.588, p = 0.450), rotation and task (F = 0.792, p = 0.566), glasses type and task (F = 0.206, p= 0.654), and rotation and gender (F = 1.379, p = 0.226). There was a significant interaction effect between gender and task (F = 9.419, p = 0.005). For the picking task, females reported lower Attachment scores (M = 12.389) than males (M = 17.352). Then for the putting task, males reported lower attachment scores (M = 11.533) than females (M = 15.833). There was no significant three or four-way interaction between any of these variables ($p > 0.05$).

Harm: There was no significant main effect for rotation (F = 0.509, p = 0.767). There was a significant main effect for task (F = 3.852, p = 0.015), with putting tasks participants reporting lower Harm scores (M = 4.652) than picking task participants (M = 7.870). There was also a significant main effect for glasses type (F = 4.895, p = 0.036), with the glasses weighted in the back having a higher Harm score (M = 8.149) than the glasses weighted on the front (M = 5.692) and the glasses weighted on the side (M = 5.152). There was a significant main effect as well for gender (F = 5.361, p = 0.029), with females reporting lower Harm scores (M = 4.648) than males (M = 8.167). There was no significant two-way interaction between glasses type and rotation (F = 1.832, p = 0.143), glasses type and gender (F = 0.136, p = 0.715), rotation and task (F = 1.297, p = 0.297), glasses type and task (F = 0.020, p = 0.888), and gender and task (F = 2.146, p= 0.155). There was a significant interaction effect between rotation and gender (F = 3.140, p = 0.025). There was no significant three or four-way interaction between any of these variables (p > 0.05).

Perceived Change: There was no significant main effect for glasses type (F = 0.030, p = 0.865), rotation (F = 1.016, p = 0.767), gender (F = 1.080, p= 0.309) and task (F = 0.074, p = 0.788). There was no significant two-way interaction between glasses type and rotation (F = 0.399, p = 0.845), glasses type and gender (F = 1.029, p = 0.320), rotation and task (F = 2.133, p = 0.095), gender and task (F = 0.241, p = 0.628), and glasses type and task (F = 3.637, p = 0.068). There was a significant interaction between rotation and gender (F = 4.139, p = 0.007). There was no significant three or four-way interaction between any of these variables (p > 0.05).

Movement: There was no significant main effect for glasses type (F = 0.910, p = 0.349), rotation (F = 0.193, p = 0.963), gender (F = 0.805, p = 0.378) and task (F = 0.199, p = 0.660). There was no significant two-way interaction between glasses type and rotation (F = 1.428, p =

0.249), glasses and gender (F = 0.113, p = 0.740), gender and task (F = 0.005, p = 0.942), glasses and task (F = 0.005, p = 0.941), and rotation and gender (F = 1.401, p = 0.258). There was a significant interaction effect between rotation and task (F = 3.647, p = 0.013). There was no significant three or four-way interaction between any of these variables (p > 0.05).

Anxiety: There was no significant main effect for the glasses types (F = 0.002, p = 0.969), rotation (F = 0.872, p = 0.513), gender (F = 3.021, p = 0.095) and task (F = 1.794, p = 0.192). There was no significant two-way interaction between glasses type and rotation (F = 0.764, p = 0.584), glasses type and gender (F = 0.784, p= 0.384), rotation and task (F = 2.390, p = 0.067), glasses type and task (F = 0.556, p = 0.463), rotation and gender (F = 1.978, p = 0.117), and gender and task (F = 0.414, p = 0.526). There was no significant three or four-way interaction between any of these variables (p > 0.05).

2.4.4   Correlations

2.4.4.1   Picking Task

A Pearson's product-moment correlation was used to analyze just the participants that completed the picking task. The analysis was run to assess the relationship between the participants' height, wingspan, and head circumference amongst 6 CRS dimensions, CRS total, average heart rate, adjustments made to the glasses, and the number of correct and incorrect completed pick lists. The results are reported in ***Table 2.9***.

Table 2.9   Correlations

Measure	Pearson Correlation								
	Front Weighted			**Side Weighted**			**Rear Weighted**		
	Height	Wingspan	Head Cir	Height	Wingspan	Head Cir	Height	Wingspan	Head Cir
Emotion	-0.214	-0.355	-0.330	-0.060	-0.219	-0.358	-0.306	-0.405*	-0.416*
Attachment	0.383	0.254	-0.152	0.105	0.134	-0.407*	0.236	0.250	-0.086
Harm	0.166	0.114	-0.191	0.173	0.195	-0.359	0.079	0.054	-0.290
Perceived Change	-0.331	-0.369	-0.321	-0.290	-0.382	-0.508*	-0.433*	-0.352	-0.161
Movement	-0.297	-0.343	-0.008	-0.326	-0.273	-0.187	-0.505*	-0.491*	-0.117
Anxiety	-0.485*	-0.481*	-0.182	-0.307	-0.331	-0.451*	-0.535*	-0.538*	-0.361
CRS total	-0.202	-0.301	-0.297	-0.178	-0.219	-0.552*	-0.349	-0.353	-0.341
Avg Heart Rate	-0.454*	-0.538*	0.070	-0.569*	-0.654*	0.013	-0.527*	-0.599*	0.035
Touches	-0.097	-0.226	-0.076	-0.255	-0.319	-0.268	-0.100	-0.102	-0.235
Completed Lists	0.039	0.047	0.073	0.064	0.061	0.181	0.220	0.328	0.196
Incomplete Lists	-0.231	-0.359	-0.135	-0.023	0.078	0.335	-0.076	-0.090	-0.097

Pearson's Correlations for height, wingspan, and head circumference (head cir) to dependent variables. (N =24, * denotes significance at $p < 0.05$)

For the glasses weighted in the front, there was a moderate negative correlation between height, and the Anxiety scores and average heart rate, and between wingspan and Anxiety scores. Also, there was a strong negative correlation between wingspan and average heart rate. For the glasses weighted on the side, there was a moderate negative correlation between head circumference and Attachment and Anxiety scores. There was a strong negative correlation between height and average heart rate, between wingspan and average heart rate, between head circumference and Perceived Change and CRS total scores. For the glasses weighted in the back it was found that, there was a moderate negative correlation between height and Perceived Change scores, between wingspan and Emotion and Movement scores, and between head circumference and Emotion scores. Also, there was a strong negative correlation between height and Movement scores, Anxiety scores, and average heart rate, between wingspan and Anxiety scores and average heart rate.

2.4.4.2   Putting Task

A Pearson's product-moment correction was used to assess the relationship between the participants' height, wingspan, and head circumference amongst the 6 CRS dimensions, CRS total scores, average heart rate, adjustments made to the glasses, and productivity of moving boxes. The results are reported in *Table 2.10*.

Table 2.10   Correlations

Measure	Pearson Correlation								
	Front Weighted			**Side Weighted**			**Rear Weighted**		
	Height	Wingspan	Head Cir	Height	Wingspan	Head Cir	Height	Wingspan	Head Cir
Emotion	0.094	0.010	-0.144	-0.031	-0.301	-0.068	0.163	0.168	0.153
Attachment	-0.051	0.001	-0.039	-0.124	-0.228	-0.109	-0.399	-0.422*	0.099
Harm	0.107	-0.147	0.068	0.183	-0.222	-0.358	0.243	0.157	0.050
Perceived Change	-0.104	-0.107	0.168	-0.020	-0.164	-0.036	-0.183	-0.065	0.271
Movement	-0.271	-0.397	-0.168	0.187	-0.050	-0.344	-0.164	-0.081	0.305
Anxiety	-0.378	-0.229	0.299	-0.286	-0.474*	-0.103	-0.328	-0.132	0.117
CRS total	-0.182	-0.237	0.107	-0.018	-0.323	-0.241	-0.180	-0.119	0.234
Avg Heart Rate	0.058	0.156	-0.160	0.071	0.214	-0.088	0.131	0.136	-0.206
Touches	-0.254	-0.331	-0.288	-0.193	-0.358	-0.217	-0.234	-0.354	-0.113
Boxes Moved	0.295	0.177	-0.223	0.313	0.240	-0.397	0.360	0.185	-0.357

Pearson's Correlations for height, wingspan, and head circumference (head cir) to dependent variables. (N =24, * denotes significance at $p < 0.05$)

For the glasses weighted on the side, there was a moderate negative correlation between the participants' wingspan, and Anxiety scores. There was also a moderate negative correlation between wingspan and Attachment scores for the participants when wearing the glasses weighted in the back.

2.4.5   Forced Choice Results

Overall the participants' main concerns when asked about wearing these glasses in a work environment was that (a) the glasses kept slipping off, (b) the device rubbing against the skin, and (c) cleanliness (*Figure 2.10*). Other concerns that the participants mentioned were that

they were worried about moving too fast, the product being impacted by glasses, how it would affect the health of their eyes and feeling unable to bend or lean forward when needed because of worrying about the glasses falling off.

Concerns with Wearing Smart Glasses
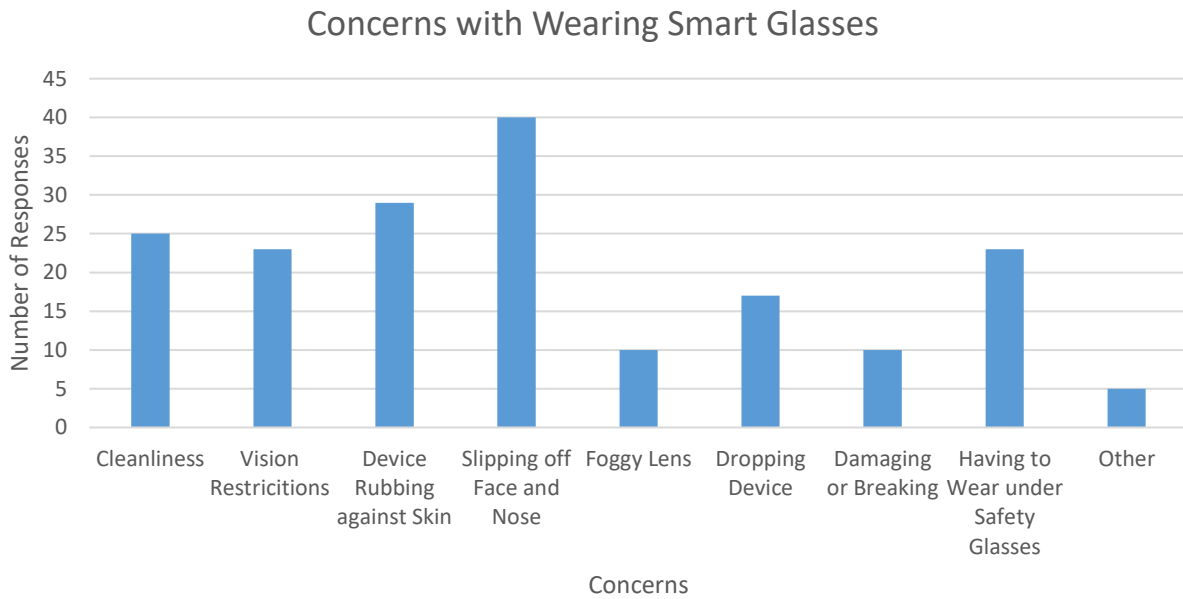
Figure 2.10   Concerns with Wearing Smart Glasses

Participant concerns about wearing smart glasses at work in an industrial environment.

2.4.5.1   Overall

A qualitative statistical analysis tool, NVivo, was used analyze the responses from the post survey. A follow up question asked the participants if they were hired to perform a task similar to the one completed for the study, would they be comfortable wearing the smart glasses for four to eight-hour shifts. Approximately 77% of the participants said they would not be comfortable.

Overall, participants reported that the smart glasses weighted on the side were the most comfortable. The smart glasses weighted in the front closely followed by the smart glasses weighted in the back were both reported as the least comfortable (*Figure 2.11*).
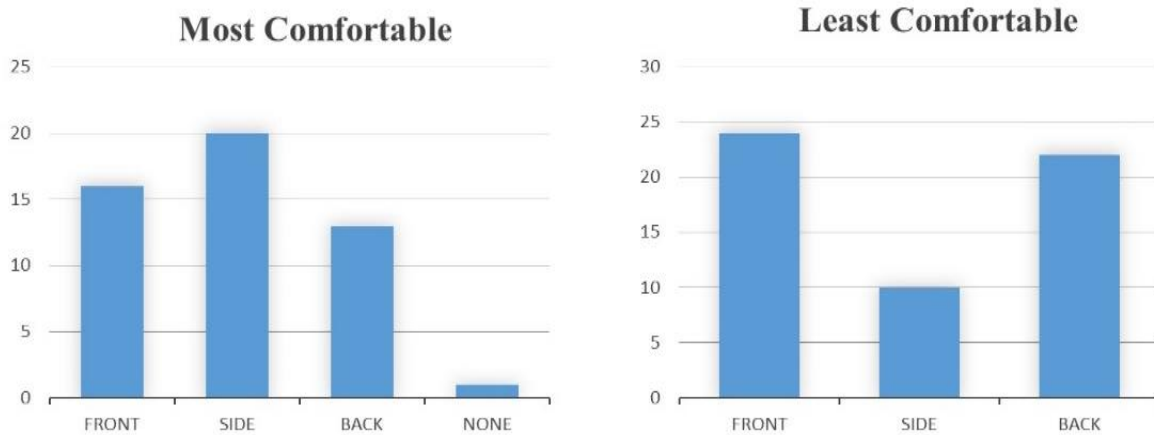
Figure 2.11   Participants Feedback on Weighted Glasses Overall

Participant rating of comfort based on how the different smart glasses were weighted for both picking and putting tasks.

2.4.5.2   Picking

The participants were asked to identify the most and least comfortable pair of glasses while completing the picking task and were given the option to select more than one answer. The participants indicated that the glasses weighted on the side and front were most comfortable. Regarding the least comfortable pair of smart glasses, the participants selected the weighted back for this task (*Figure 2.12*).
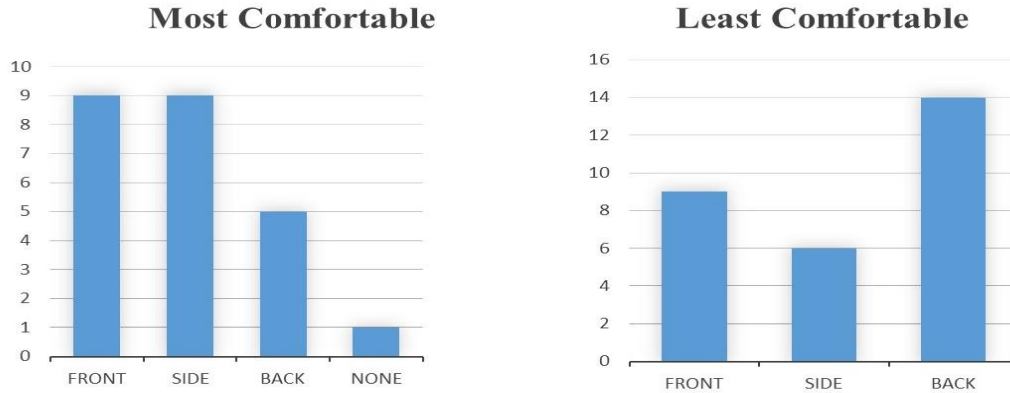
Figure 2.12   Picking Task: Participants Feedback on Weighted Glasses

Participant rating of comfort based on how the different smart glasses were weighted for only the picking task.

2.4.5.3   Putting

When asked which pair was the most comfortable, participants who completed the

putting test identified that the glasses weighted on the side where the most comfortable to wear,

while the glasses with the weight placed on the front was the least comfortable (*Figure 2.13*).
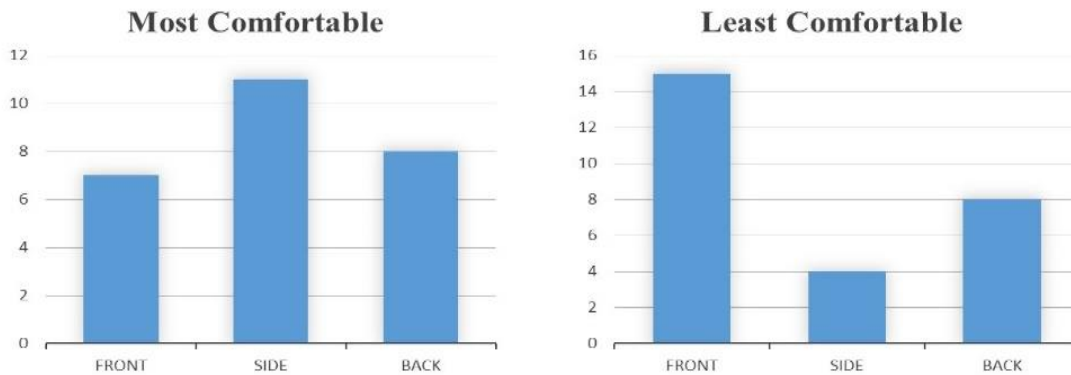
Figure 2.13   Putting Task: Participants Feedback on Weighted Glasses

Participant rating of comfort based on how the different smart glasses were weighted for only the putting task.

2.5   Discussion

The purpose of this study was to use the CRS, the participants' questionnaire responses and their physical responses to the glasses (including performance) in order to provide a recommendation on where to add weight to smart glasses in such a way that doesn't impact comfort for the user. For the putting task, it was reported by the users that the glasses weighted on the front was the most uncomfortable pair of smart glasses. The front weighted arrangement also received the highest (most negatively perceived) Emotion and Movement CRS scores for the picking task and the highest Attachment, Perceived Change and Anxiety CRS scores for the putting task. The device preference for the glasses was weighted side but the performance across the weighted glasses remained consistent.

There was not a significant difference in device preference regardless of task type. The glasses weighted on the side were the most comfortable pair for the picking and putting tasks. Despite the side weighted arrangement being the most comfortable pair of smart glasses, the participants were still uncomfortable wearing them. The participants recommended securing the glasses to the face by adding a strap or making the glasses adjustable to different head sizes while finding a way to distribute the weight evenly. Participants expressed interest in having options as they believed this would help make wearing the glasses a more enjoyable experience. Device configuration preference was not significantly impacted by head dimensions and height.

With regards to comfort, analysis of the six dimensions of the CRS tool highlighted that, while wearing the weighted Vuzix® glasses, the participants experienced moments of being uncomfortable. Specifically, the CRS revealed:

A. Emotion – reported low CRS scores in comparison to the other dimensions, meaning that the participants were minimally concerned about how they looked and felt only a small amount

31

of tension when wearing the device. Participants who completed the picking task that have longer wingspans and bigger head circumferences reported lower scores while wearing the glasses weighted in the back than those with smaller wingspans. As smart glasses are becoming more known and popular, awareness could have contributed to these low scores.

B. Attachment – these were the highest reported CRS scores for the picking and putting tasks. The participants experienced the glasses moving often and could feel the device on their face. The results from the picking task demonstrate that while wearing the glasses weighted on the side, participants with a bigger head circumference reported lower scores than those with a smaller head circumference. The participants with a longer wingspan who completed the putting task while wearing glasses weighted in the back reported lower scores than participants with a shorter wingspan.

C. Harm – the device was identified as somewhat painful to wear indicating that a design changes need to be considered.

D. Perceived Change – when wearing these devices, the participants reported feeling strange, awkward, and/or physically different. When wearing the smart glasses weighted on the side, the participants who completed the picking task that had larger head circumference reported lower scores than those with a smaller head circumference. Also, while completing the picking task and wearing the glasses weighted in the back, the participants who are taller reported lower scores than shorter participants.

E. Movement – some participants reported that their movements felt restricted in order to prevent the glasses from sliding and falling off of their face and that the glasses slowed them down from a process efficiency perspective. Picking task participants who are taller and have

longer wingspans reported lower scores while wearing smart glasses weighted in the back than those with a shorter wingspan.

F. Anxiety – participants reported that they did not feel secure wearing the smart glasses. Those that participated in the picking task did experience more anxiety than those that participated in the putting task. The results from the picking task show that while wearing the glasses weighted on the side, participants with a bigger wingspan and head circumference reported lower scores than those with a smaller head circumference. While wearing glasses weighted on the front during the picking task, taller participants reported lower scores than the shorter participants.

One of the emphasized benefits for AR devices is the ability to have a portable computer device that can be worn while keeping workers' hands free to complete other tasks. The participants were able to have their hands free from holding technology so that they could move the boxes and pick the items which agrees with Stoltz et al. (2017) who thought that AR would provide flexibility to the workers. The findings from this study also agree with the Brusie et al. (2015) findings that the uneven weight distribution on the glasses could lead to discomfort for long-term wear.

The hardware of AR can provide a limitation for using smart glasses in the warehouse. Stolz et al. (2017) acknowledged the current battery life for AR devices is short and as a result would require workers to carry extra batteries which is logistically impractical for large industrial companies with large numbers of both employees and equipment. While adding additional, modular battery capacity directly to an existing pair of smart glasses is certainly an option, this study reveals that adding weight to frames to offer a possible solution can also be perceived as a burden to some of the participants from a comfort perspective. Also, having a hands-free device

might not be the safest alternative to physically holding asset tracking/assistance technology. Workers needing to constantly adjust the glasses on their face could end up creating a safety hazard for themselves or others in a busy industrial environment.

"The glasses are weighted and it affects my natural range of how I move my head so the glasses won't fall."

An important indicator as to whether AR will be successfully implement in warehouse operation environments is user perception of the device and knowing if targeted worker groups will be willing to wear smart glasses for long periods of time while performing tasks (***Figure 2.14***). The participants were asked if they were hired for a job that required them to commonly perform the same task from the study, would they want to use smart glasses to assist with the process. Approximately 90% of the participants said they would not want to use smart glasses.

"They weren't comfortable to wear and they were a distraction to the task"

"They were also heavy on the right side and lighter on the other side so it was uncomfortable."
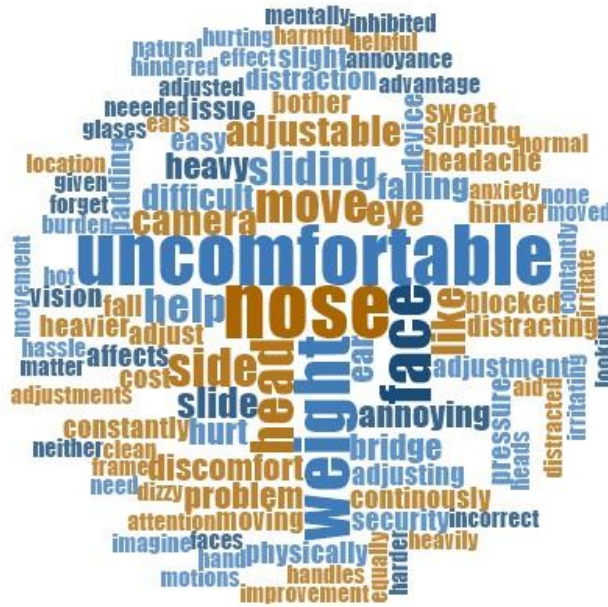
Figure 2.14   Word Cloud

Word cloud represents the participants opinions about using these glasses in a similar work environment.

Another issue with the glasses was that the participants felt like the wearable hindered their movements. As a result, their task progress was slowed.

"I felt the glasses got in the way of doing my job."

"The glasses were uncomfortable and prohibited me from moving as fast as I could."

A few participants noted in the comments experiencing symptoms of pain in their head, and on their ear and nose while wearing the Vuzix® glasses.

"The glasses hurt sitting on my nose."

"They were already beginning to slide down my nose within 5-10 minutes and I noticed a slight headache towards the end of each trial."

Granted, the Vuzix® device did not have an application installed to assist with the task; therefore, their responses were largely based on comfort. These findings are different from Stoltz

et al (2017), who thought that the new technology would cause an easier acceptance in the industry especially for the younger generation.

2.6 Conclusion

This study demonstrates that more research should be completed to understand the best way to alter the smart glasses without compromising comfort for the users. With the weight placed in different areas, the participants managed to complete about the same number of pick list and moved approximately the same number of boxes for each case. For this reason, the weighted glasses did not have an impact on their production based off the data but from their responses, the participants felt that wearing the glasses hindered their performance. In conclusion, people reported that they did not like wearing the smart glasses while completing the picking or putting tasks. For companies thinking about investing in smart glasses, other alternatives to add memory or battery life should be considered instead of adding more weight to the frame and AR device.

2.6.1 Limitations

This study experienced a few limitations due to technology issues, the demographics of the participants, and experimental design of the study. There were a few issues with the Vuzix$^{®}$ battery dying during the study and the Polar$_{®}$ heart rate monitor losing contact with the participants' skin, causing a loss of some of the participant's heart rate data. Since the participants recruited were college students, recruiting targeted young adults who lacked experience in repetitive task work. Many of the participants were not familiar with smart glasses and did not understand the purpose for the glasses while completing the tasks. More time should have been set aside to explain why the use of smart glasses were beneficial to picking and

putting tasks at the beginning of the experiment. The study was designed to be completed within

a reasonable amount of time which only allocated 20 minutes for each session before assessing

comfort. Also, with the focus being centered on comfort, the camera application was used

instead of designing or finding an existing AR application to be used for the study.

CHAPTER III

AN EXAMINATION OF THE SIX FACTORS THAT IMPACT USER COMFORT OF

WEARABLE DEVICES

3.1   Introduction

The concept of comfort is misunderstood in literature due to the inability to define it in a

standardized manner. There are many factors that impact comfort, such as posture, how a person

sits, temperature, and environment (Pearson, 2009). While comfort is defined differently in

various research, three aspects associated with comfort are not debated: a) comfort is subjective,

b) there are three different forms of comfort experience (physical, physiological, and

psychological), and c) comfort is the reaction to an environment (De Looze, Kuijt-Evers, & Van

Dieën, 2003; Pearson, 2009). Employers are interested in studying comfort in order to create a

stimulating work environment that is also healthy for employees (De Looze et al., 2003). The

workers of the company play more of a crucial role in its success than machines due to their

flexibility and ability to justify changes that need to be made (Kudelska & Pawłowski, 2019).

Similar to the concept of comfort, wearable technology has also been the focus of recent

research in many different fields of study. These fixtures are used on the external parts of the

body and can be an accessory or attached to an item of clothing. Wearable devices include, but

are not limited to, watches, wristbands, necklaces, and glasses (Yang, Jieun, Zo, & Choi, 2016).

These devices offer a portable miniaturized solution that allows users to communicate and access

information on the move (Gemperle et.al, 1998). Gemperle et. al (1998) identified the need for

understanding how the wearables impact the human body. The Comfort Rating Scales (CRS), created by Knight and Baber (2005), is a tool made to analyze user comfort of wearable computer devices to assist with the design and implementation of this technology into the workforce.

Currently, the CRS is unlike any other scale that has been used in previous research. This scale measures comfort when using wearable computers based on six dimensions: emotion, attachment, harm, perceived change, movement, and anxiety. A potential issue with the current scale is that all dimensions are weighted equally. Realistically, people may have different levels of comfort that can be experienced throughout the various dimensions. Others may view some dimensions as being much more important given certain contexts: environments, tasks, and wearable device placement. Further, the CRS was created back in 2005. As electronic components have seen reductions in size, so too have wearables become miniaturized and less invasive. This study used a survey to determine the perception of the importance between the six different CRS dimensions. After survey data was collected, weights were applied using the NASA TLX to each dimension to allow for a more accurate evaluation of comfort. The purpose of this study was to determine if modifying the current CRS by adding a weight system created a better understanding of comfort evaluation when using wearable devices.

3.2   Literature Review

Presently, the tools used to assess perceived comfort of users are the visual analog scale (VAS), anatomical illustration rating scale, the Borg Scale, category ratio scale, and the CRS (Jacobson et. al, 2004; Knight & Baber, 2005; Legg, Perko, & Campbell,1997). Some researchers have created their own comfort questionnaire assessments for their participants to complete. In a previous study, a rating scale from 0 'comfortable' to 4 'extremely

uncomfortable' was created to accompany a questionnaire to assess range of motion and comfort in various firefighter uniforms (Ciesielska-Wróbel, DenHartog, & Barker, 2017). The Body Part Discomfort scale has also been applied in different studies to assess discomfort by having users mark on a body chart where they are uncomfortable and rate it (Kölsch, Beall, & Turk, 2003). The purpose for considering both comfort and discomfort is because the lack of comfort and discomfort are not the same thing (van der Steen et al., 2015). Feelings of discomfort are associated with pain, tiredness, soreness, and numbness (De Looze et al., 2003; Helander & Zhang, 1997). Other factors that influence the feeling of discomfort are repetition, force and posture (Bano, Mallick, & Khan, 2016). These scales have also been used to measure postural and thermal comfort, muscular fatigue, and pain (Fontana, & Sazonov, 2013).

Perception of comfort is influenced by how a person is feeling and should be evaluated subjectively (Pearson, 2009). Previous studies viewed comfort as a one-dimensional construct, but Knight et. al (2002) believed that this was a limitation and argued that comfort should be measured across many dimensions because of its complexity. The CRS was created by Knight and Baber to measure user comfort when wearing and using wearable computers. They used the NASA-TLX as a reference, and created six dimensions to measure comfort: emotion (concerns with appearance), attachment (feeling the device physically on the body), harm (damage to body), perceived change (feeling different), movement (affects user movement), and anxiety (worrying about device, safety, and reliability) (Knight et al., 2002). *Table 11* below provides the written descriptions for each of the scales. The scales utilize a 21-point system that is labeled from 0 'low' to 20 'high' for each statement. In 2006, Knight et. al completed another study to assess wearability of wearable computers while capturing physiological and biomechanical

effect, and comfort assessment. Based on their findings, Knight proposed that all wearable systems need to be evaluated to ensure usability, satisfaction and safety.

Table 3.1   CRS Subscale Descriptions

Dimension	Description
Emotion	I am worried about how I look when I wear this device. I feel tense or on edge because I am wearing this device.
Attachment	I can feel the device on my body. I can feel the device moving.
Harm	The device is causing me some harm. The device is painful to wear.
Perceived Change	Wearing the device makes me feel physically different. I feel strange wearing the device.
Movement	The device affects the way I move. The device inhibits or restricts my movement.
Anxiety	I do not feel secure wearing the device.

CRS statements that are rated on a scale from 0 (comfortable) to 20 (uncomfortable).

A literature search using academic search engine (EBSCO) and Google Scholar was conducted to see the prevalence of CRS in research. The following search terms were used: comfort rating scales AND wearables, wearable technology, wearable computer, wearable sensors, wearable devices, industrial wearables AND comfort, discomfort, AND assessment. Abstracts were used to determine if the articles that appeared in the search were relevant for this research. The reference section was also reviewed to identify articles that were relevant to find

additional sources. A reverse citation lookup on Google scholar was conducted to find articles that used CRS by searching for articles citing Knight's work. Articles were retained for inclusion if they were assessing the comfort of wearable devices using the CRS. Papers were excluded if they mentioned CRS but did not apply it to their study. A total of 53 articles were identified through this process. Thirty-seven of the papers found utilized the CRS as a tool to measure comfort when using wearable devices or sensors.

Knight and Baber (2005) used four different wearable products that could be worn on the arm (weighs 85 g), head (weighs 1.12 kg), hand (weighs 180 kg), and an over the shoulder pouch (weighs approximately 600 g). All four of these devices were evaluated while sitting, walking, and moving around within a 30-minute session (Knight & Baber, 2005). In 2002, Knight and Baber applied the CRS to two wearable computer products that were being developed, a shirt with sensors (weight not reported) and over the shoulder bag (weighs approximately 600g). These devices were tested by asking participants to assess during general, throwing and dynamic conditions for at their leisure. Along with Knight's publications, the CRS has been applied to devices used in the health field (Charness, Best, & Evans, 2016; Voinea, & Butnariu, 2017), gait (Mazilu et al., 2013; Murata, Suzuki, & Fujinami, 2013; Mazilu et al., 2014) and devices used to monitor physical activity (Hassan, Daiber, Wiehr, Kosmalla, & Krüger, 2017; Meyer, Fortmann, Wasmann, & Heuten, 2015). Previous work used the CRS to test wearability of a spine posture monitoring device (Voinea, & Butnariu, 2017), evaluate chewing and swallowing sensors (Fontana, & Sazonov, 2013), access telemonitoring using a wearable computer system for an intensive care unit (Weller, Rakhmetova, Ma, & Mandersloot, 2010), and examine sensors used for patients with Parkinson's disease (Tsipouras et al., 2012). These devices were evaluated in a range of different periods of 10 to 90 minutes and a maximum of 6 months to evaluate comfort.

The interpretation of the CRS results varied among the different research studies. There was a total of nine articles that used alternative Likert scales to accompany the different criterion. Prior research studied the functionality of a wearable armband and backpack and assessed comfort using the CRS on a 10-point Likert scale (Bodine, & Gemperle, 2003). Another study assessed comfort of various sizes of sensors when chewing and swallowing, the researchers took the comfort statements, but used a 10-point scale that ranged from 0 meaning lowest agreement to 10 being highest agreement (Fontana, & Sazonov, 2013). Two studies used a Likert scale that ranged from -10 (negative feelings) to 0 (neutral feelings) to 10 (positive feelings) (Beeler et al., 2018; Tharion et al., 2013). Three of the studies used 7-point Likert scales that ranged from 1 (disagree completely), 4 (neutral), and 7 (completely agree) (Charness et al., 2016; Choi, Ahmed, & Gutierrez-Osuna, 2010; Fang, Hsu, Hsun, & Chang, 2013)). Additionally, two articles applied a Likert scale that ranged from 1 (low) to 5 (high) (Mazilu et al., 2013; Tzallas, 2014). Another study applied a 6-point Likert Scale to the CRS and defined 1 as completely disagree (Spagnolli, Guardigli, Orso, Varotto, & Gamberini, 2014).

Modifications were also made to add or only use specific dimensions from the CRS. In one study another dimension was added to capture the benefits of different chewing sensor sizes (Fontana, & Sazonov, 2013). The CRS was also changed in a study to include aesthetics-related items (Charness et al., 2016). An additional study modified the CRS to add three questions for perceived change and physical effect, and two questions for anxiety listed in the table below for theater garb (Malik, Handford, Staniford, Gambhir, & Kay, 2006). Two studies that researched gait only used CRS dimensions attachment, harm, perceived change, and movement (Mazilu et al., 2013; Tzallas, 2014).

The research performed in this study tests another CRS modification: adding weights to each of the comfort dimensions in order to generate a meaningful composite score. The CRS was designed using the NASA TLX as a reference as it is a known, validated tool for measuring mental workload (Knight et al., 2002). The NASA TLX uses the data collected to calculate an overall workload score based on a weighted average of the subscales. Currently, analysis completed using the CRS does not include calculating a comfort score. Just like the NASA TLX it is believed that including the weighting provides a way to get a more representative score that can be beneficial for interpreting results (Wiebe, Roberts, & Behrend, 2010). The purpose of this study was to identify if one of the attributes are more of a concern for the user than the other attributes when wearing wearable devices; then use that information to create a composite score representative of the users perceived comfort level.

3.3   Methods

This study was designed to be conducted online using Amazon Mechanical Turk and Qualtrics. Approval for this study was given by the Institutional Review Board at Mississippi State University before the data was collected. This section will describe the participants, procedures, the survey and how the data was analyzed.

3.3.1   Participants

Participants recruited were 18 and older, located in the United States with at least 100 prior jobs on Amazon Mechanical Turk. A link was posted on the website to allow potential participants the ability to access the survey. Once the survey was completed, participants were compensated $1.00. If the participant provided the same answer when asked which dimension was the most and least important, the answer was considered an illogical and not used for this

study. Responses from participants who missed the attention question when completing the survey were not used. The data of 400 participants who completed the survey without missing the attention question and without providing an illogical answer choice was used to complete the analysis. Participants ages ranged from 20 to 87 years old (M = 34.6, SD = 9.8) with 61.8% identified as male, 37.8% as female and 0.5% as categories other than male or female. Most of the participants had experience with wearable computer devices (73.3%) and personal protective equipment or PPE (88.0%). Additionally, some of the participants with wearable technology experience spent more than 8 hours using wearable technology (16.3%) and wore wearable technology on their wrist (55.8%). Also, those who had experience with PPE spent less than one hour using it (42.3%) and wore PPE on their face (55.5%), head (50.0%) and hands (45.5%). Additional information about the participants' experience with wearable technology and PPE is provided in *Table 3.2*.

Table 3.2   Report of Participant Experience

Question	Answer Choices	Wearable Technology (%)	PPE (%)
Have you had experience with wearable technology/PPE?	**Yes**	73.3	26.8
	No	88.0	12.0
I wear wearable technology/PPE on my…….?	**Head**	15.0	50.0
	Face	10.8	55.5
	Waist	5.3	7.3
	Chest	5.5	11.3
	Arm	12.3	9.0
	Wrist	55.8	8.8
	Ankle	3.0	45.5
	Other	0.8	3.8
On average, how many hours a day do you spend using wearable technology/PPE?	**Less than 1 hour**	12.5	42.3
	1-2 hours	12.5	15.0
	2-4 hours	13.0	14.8
	4-6 hours	11.5	6.8
	6-8 hours	7.5	7.3
	More than 8 hours	16.3	2.0
When have you worn/used wearable technology/PPE?	**Work**	51.5	67.8
	School	19.3	16.3
	Home	50.0	44.3
	While Exercising	47.3	--
	Other	1.3	1.5
Why do you use wearable technology?	**Required for my job**	19.8	--
	Entertaining	26.8	--
	Everyone has one	6.0	--
	Track heart rate/activities	49.8	--
	Others	2.3	--
While wearing wearable technology/PPE they can be uncomfortable on my	**Ear**	17.0	32.3
	Nose	12.8	35.0
	Wrist	21.8	11.0
	Waist	6.3	6.8
	Chest	6.8	7.5
	Arm	7.0	8.8
	Ankle	6.3	3.8
	Other	0.8	6.3
	Comfortable	25.0	22.8
	None of the above	5.8	7.8

Additional information about the participants experience with wearable devices and PPE.

The characteristics of wearables and how they are worn is similar to the PPE that has already been implemented in industry. Companies require the use of PPE such as hard hats, safety glasses, face shields, coveralls, foot protection, and safety harnesses to protect employees from the dangers of their work environment (Flynn, Keller, & DeLaney, 2017). Prior research studied factors that impacted the use of safety glasses (Lombardi, Verma, Brennan, & Perry, 2009) and how to get workers to wear them (Monaghan et al., 2012). One of the factors that impacted the use of safety glasses was comfort. In the first study, a participant reported that the safety glasses are made for men, and do not fit women workers properly creating the need for constant adjustment (Lombardi et al., 2009). In the other study, the researchers tested 20 commercially available safety glasses and asked for feedback to enhance comfort and performance. In the beginning of the study, the workers perceived the glasses as uncomfortable. But after using the glasses longer during a trial period, the workers realized their assumptions were incorrect. The researchers identified the value of using a trial period to help with the adoption of safety glasses (Monaghan et al., 2012). Participants could relate their experience with PPE to using wearable devices because these products are additionally worn to perform a task.

3.3.2   Procedure

Potential participants followed the link provided on the Mechanical Turk website and were rerouted to complete this study's survey created on Qualtrics. The first part of the survey was an informed consent form that participants were asked to read and acknowledge consent in order to participate in the study. Once consent was given, participants read through a wearable scenario (See Appendix A). After reading the scenario, participants were asked to assess perceived comfort by completing the CRS.

The administration of the CRS was divided into three parts. First, the participants evaluated each of the six dimensions based on perceived comfort of completing the task from the scenario and identified which dimension was most and least important. Second, participants were asked to complete 15 pairwise comparisons of the six factors of comfort. Each comparison was displayed on the screen in a randomized order and the user would select the answer in the answer box. The third part of the survey asked participants to answer demographic questions such as gender, age, and their experience with wearable technology and PPE. Once the survey was completed, the participants were provided with an identification number to submit in Mechanical Turk website to be compensated.

3.3.2.1   Scenario

Two scenario questions were created that described a person using either a ring scanner or smart glasses while working at a job. The survey was randomized so that half of the participants would read through the ring scanner scenario while the other half would read the smart glasses scenario. At the start of the survey, participants were first asked to read through the wearable device scenario (ring or glasses) that was randomly assignment to them. Included in the scenario was information about the specific task that the worker was completing, weight of the wearable device, and description of the six dimensions used to measure comfort to evaluate their experience. Then the participants were asked to complete the CRS based on the scenario they read.

3.3.2.2   Weighting Comfort Rating Scales

The overall comfort score was calculated by averaging the subscale ratings and using the NASA TLX weighting technique (Hart, & Staveland, 1988) as shown in *Figure 3.1*. After the

participants completed the 15 comparisons (***Figure 3.1a***), the data was used to calculate the

weights. Each dimension could be picked between 0 (not relevant) to 5 (relevant) times. The

researcher then tallied the number of times each dimension was identify how much each

dimension would be weighed (***Figure 3.1b***). The ratings provided from the participants after the

reading of the scenario was used to calculate the unweighted (***Figure 3.1c***) and weighted (***Figure***

3.1d) comfort scores. Weights where calculated per participant.
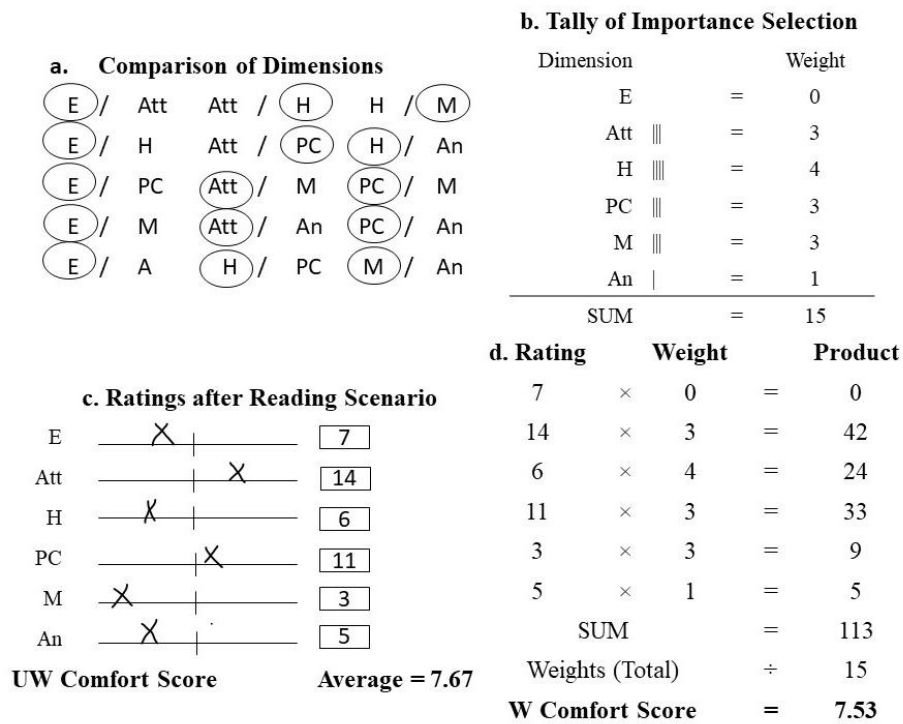
Figure 3.1   Calculation of Comfort Scores

Example data used to show how the unweighted (UW) and weighted (W) comfort scores were
calculated.

3.3.3   Statistical Analysis

The data collected from the study was used to apply weights to the six CRS dimensions:

emotion, attachment, harm, perceived change, movement, and anxiety using the method created

for the NASA TLX. SPSS and Microsoft Excel were used to disaggregate the data collected from the surveys. Appropriate descriptive statistics were calculated. A two independent samples t-test was used to identify significant differences between the wearable scenario for the comfort score. One-way ANOVA was run to analyze the effect the perception of user comfort of device for age and gender. Pearson correlation coefficient was calculated to determine the relationship between the weighted and unweighted comfort score.

3.4   Results

All statistical analyses were conducted in Microsoft Excel and SPSS. *Table 3.3* reports the mean weighted and unweighted comfort scores by ring scanner and smart glasses scenario by demographics. Potential participants that missed the attention question or had an illogical answer were removed from the analysis. A total of 400 responses was used for this analysis.

Table 3.3   Report Mean Comfort Scores by Scenario

Scenario			Ring Scanner			Smart Glasses	
Demographics		N	Mean(SD) W	Mean(SD) UW	N	Mean(SD) W	Mean(SD) UW
Overall		206	8.37(4.83)	7.69(4.57)	194	9.59(4.68)	8.80(4.41)
Age	18-29	80	8.44(4.99)	8.13(4.85)	60	9.91(4.15)	9.31(3.93)
	30-39	88	8.11(4.54)	7.15(4.12)	91	9.40(4.92)	8.65(4.73)
	40-49	21	9.06(5.58)	8.49(5.40)	22	9.85(4.93)	8.67(4.55)
	50-59	11	9.96(5.20)	8.85(4.54)	13	10.40(5.09)	4.53(1.26)
	60-69	5	5.85(2.82)	4.77(2.93)	7	6.99(4.99)	3.91(1.48)
	70+	1	5.40	5.33	1	9.93	8.83
Gender	Male	123	8.43(4.79)	7.71(4.49)	124	8.92(4.54)	8.27(4.37)
	Female	82	8.25(4.93)	7.63(4.74)	69	10.78(4.77)	9.76(4.37)
	Other	1	10.00	10.67	1	10.07	7.50

Reports the mean weighted (W) and unweighted (UW) comfort scores by demographics.

A two independent samples t-test was used to compare the mean weighted comfort score for the ring scanner and smart glasses scenario. The results indicated that there was a statistically significant difference between the mean comfort scores for different scenarios (t = -2.570, p = 0.011). The smart glasses scenario had a significantly higher mean weighted score for comfort score (M = 9.59) than the ring scanner (M= 8.37). There was no significant difference in the weighted comfort scores based on age for the ring scanner [$F(5, 200)$ = 0.723, p = 0.607] and smart glasses scenario [$F(5,188)$ = 0.603, p = 0.698]. For the analysis of significance based on gender those that identified as other than male or female were omitted from this analysis. There was no significant difference for weighted comfort score based on gender for the ring scanner [$F(1,203)$ = 0.066, p = 0.797]. There was a significant difference between the weighted comfort

score and gender for the smart glasses scenario [$F(1,191) = 7.153$, $p = 0.008$]. The mean comfort scores for females (M = 10.78) was significantly higher than the males scores (M = 8.92). The analysis was completed again with the unweighted comfort score and the results reported the same findings.

The relationship between weighted and unweighted comfort scores was assessed. The composite comfort score was calculated by averaging the raw subscale scores and by using the weighting technique created for the NASA-TLX (Hart & Staveland, 1988). The correlation between the scores was $r = 0.95$, $p < 0.001$ overall (***Table 3.4***). The correlation between the scores based on device was $r = 0.96$, $p < 0.001$ for ring scanner and $r = 0.94$, $p < 0.001$ for the smart glasses. Thus, there was a strong relationship between the weighted and unweighted comfort scores.

Table 3.4   Correlation of Weighted and Unweighted Comfort Scores

	N	r
Overall	400	0.95***
Ring Scenario	206	0.96***
Glasses Scenario	194	0.94***

* $p < .05$, ** $p < .01$, *** $p < .001$

3.4.1   Weights

The comfort scores for each dimension by scenario are compared in the graph in ***Figure 3.2***. Overall across both devices the general pattern was Attachment scoring the highest followed by Perceived Change, Movement. Participants scored Anxiety the lowest for the ring scanner and Emotion the lowest for the glasses scenario. A one way ANOVA reported that there was no significant difference for Emotion ($F(1,398) = 0.038$, $p = 0.845$), Attachment ($F(1,398) = 2.450$, $p = 0.118$), and Movement ($F(1,398) = 3.072$, $p = 0.080$). There was a significant difference for

Harm (F(1,398) = 5.380, p = 0.021), Perceived Change (F(1,398) =7.950, p = 0.005), and

Anxiety (F(1,398) = 8.161, p = 0.005).
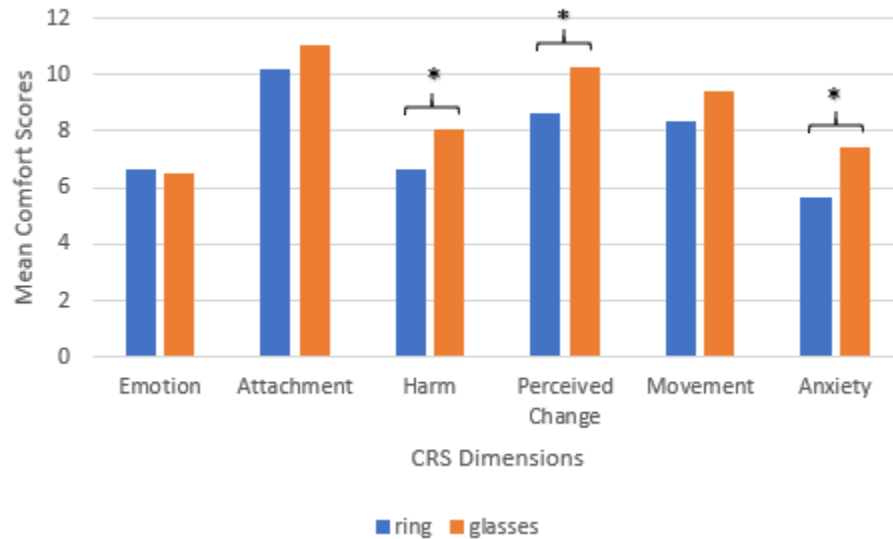
Figure 3.2   Reported Mean of Individual CRS Scores

Comparison of the mean comfort scores for each of the six dimensions. (* represents significant difference between mean comfort scores)

The descriptive statistics from the pairwise comparison are reported in *Table 3.5*.

Participants were asked which of the dimensions did they perceive to be the most and least

important. The results revealed people are most concerned about Harm and Attachment (***Figure

3.3***), and least concerned about Emotion (***Figure 3.4***).

Table 3.5   Pairwise Comparison

	N	Mean	SD	Min	Max	Median
Pairwise comparisons of CRS						
E_vs_Att	400	1.65	0.478	1	2	2
E_vs_H	400	1.68	0.466	1	2	2
E_vs_PC	400	1.61	0.488	1	2	2
E_vs_M	400	1.69	0.464	1	2	2
E_vs_An	400	1.60	0.491	1	2	2
Att_vs_H	400	1.60	0.491	1	2	2
Att_vs_PC	400	1.44	0.493	1	2	1
Att_vs_M	400	1.59	0.493	1	2	2
Att_vs_An	400	1.45	0.498	1	2	1
H_vs_PC	400	1.36	0.480	1	2	1
H_vs_M	400	1.40	0.490	1	2	1
H_vs_An	400	1.31	0.463	1	2	1
PC_vs_M	400	1.62	0.486	1	2	2
PC_vs_An	400	1.46	0.499	1	2	1
M_vs_An	400	1.33	0.471	1	2	1
Total preference of pairwise comparison						
E	400	1.77	1.68	0	5	1
Att	400	2.58	1.29	0	5	3
H	400	3.22	1.80	0	5	4
PC	400	2.33	1.40	0	5	2
M	400	2.96	1.36	0	5	3
An	400	2.14	1.42	0	5	2

Report of the descriptive statistics of the pairwise comparison. (E = Emotion, Att = Attachment, H= Harm, PC = Perceived Change, M = Movement, An = Anxiety)
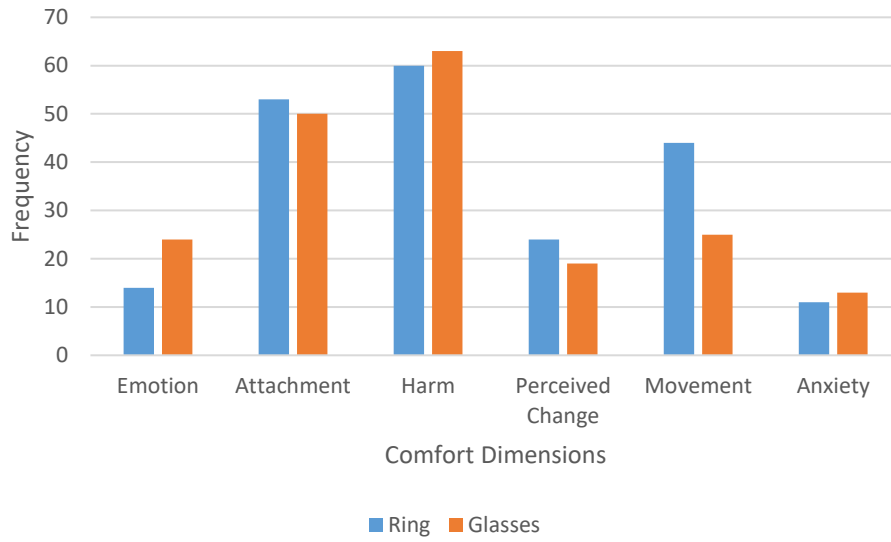
Figure 3.3   Participant Identify Most Important CRS Dimension

Most important dimension from participant feedback.
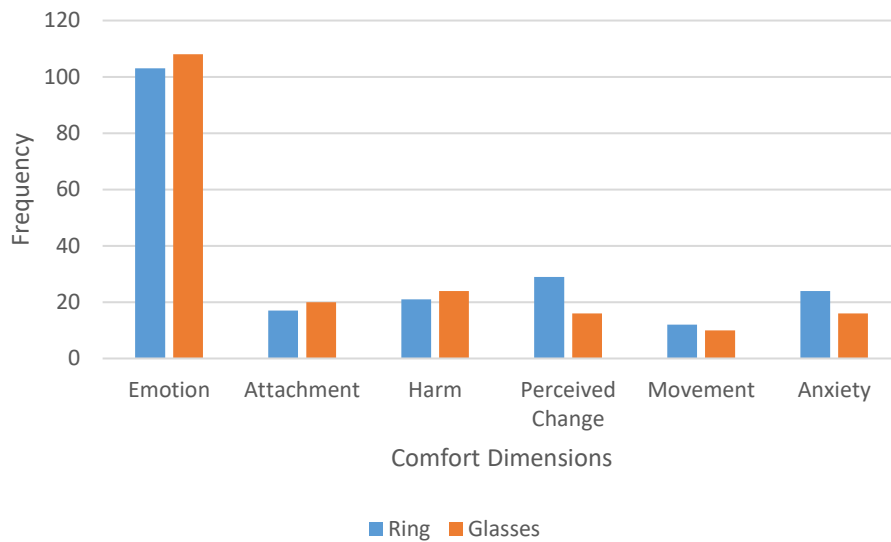
Figure 3.4   Participants Identify Least Important Factor

Least important comfort dimension based on participant feedback.

3.5   Discussion

The purpose of this study was to assess the addition of weights to the CRS based on individual preference to create a comfort score. Statistical analysis determined that there was no significant difference between the weighted and unweighted comfort scores. Similar results were found when research was conducted on assessing the weighted versus unweighted scores for the NASA TLX. Researchers reported high correlations between weighted and unweighted workload scores (DiDomenico, & Nussbaum, 2008; Noyes, & Bruneau, 2007; Wiebe et al., 2010). DiDomenico and Nussbaum (2008) recommend the elimination of the weighting from the process.

This survey allowed the participants to assess their perceptions of comfort of using a wearable device in a work setting.   Participants perceived that the use of the smart glasses would be more uncomfortable than using the ring scanner. Participants rated Harm, Perceived Change and Anxiety significantly higher for the glasses than the ring scanner. This indicates that participants perceived that using the glasses could be painful. Also, that they have concerns about the glasses causing them to feel physically different. Attachment, Perceived Change and Movement were rated the highest out of all six dimensions for the ring and glasses. This highlights that participants are physically aware of the changes made to their body. Knight et. al (2006) found similar results.

The hypothesis for this study was to determine if participants would perceive one dimension as more of a concern when wearing wearable devices than the others. An examination of the individual dimensions indicated that Harm was perceived as the most important dimension for the ring scanner and glasses scenario. Participants reported moderately low scores for Harm for the ring scanner and smart glasses scenario suggesting that they do not perceived the device

being very harmful to the body. However, further research needs to be conducted to understand if the action of completing the tasks using these devices would change the users' opinions.

Gender was found to have an impact on the perceived user comfort of wearing smart glasses to complete a task at work. Women perceived the smart glasses as more uncomfortable than men. Bodine and Gemperle (2003) concluded that there are differences in how men and women perceived the functionality and comfort of wearable technology. Another study found that women were more concerned about how they look when wearing a wearable device than men (Voinea, & Butnariu, 2017). Age did not appear to be a factor for both scenarios.

Emotion was considered to be the least important and was rated lower in comparison to some of the other dimensions when the CRS was completed. This suggests that users are more concerned with how the device impacts their body and were less concerned about how it made them feel. The level of importance assigned when asked was found to be the same for the ring scanner and smart glasses scenarios.

For the ring and smart glasses scenarios, the attachment scores were rated the highest. In earlier research, attachment was also rated high for when four different wearable devices were tested (Knight & Baber, 2005). This suggests that more focus should be spent on the physical design of wearable devices such as weight, size, placement, and attachment (Knight et al., 2002). With the current design of wearables users noticeably feel and perceive that they will be mentally aware of the device on their body.

Based on these results it is recommended to not incorporate the weighted score into the analysis of user comfort. The CRS created 17 years ago can still be considered a valid and reliable tool that can be used to measure user comfort of wearable devices no matter the placement. After evaluation of the perceived comfort scores for each dimension, the smart

glasses and ring scanner are considered wearable, but some changes need to be made to both devices to improve comfort. Customer concerns of being harmed when wearing wearable devices should be heavily considered when creating or improving wearable technology. Wearing wearable devices without understanding how the device will impact the user can have an impact on their health and safety (Knight et al., 2006).

3.6   Conclusion

Knight and Baber created a useful tool to assess user comfort of wearable devices that is still relevant and necessary today. The benefit of adding weights to create a comfort score was not reflective in the analysis. As a result, the CRS can maintain its reputation as an easy to use scale. The results show that there is also a benefit of assessing the perception of comfort without completing the task. Although the results might vary due to the experience, the information provided could help in the development phase of wearable devices.

3.6.1   Limitations

A limitation of this study is that not all participants had experience with wearable technology. As a result, they may have made different decisions about their perceived comfort had they been exposed to the devices. Another limitation is that the participants did not actually complete the task before completing the CRS and pairwise comparisons. This could have impacted how they perceived their comfort levels for the different dimensions. Future research could focus on capturing user feedback on how to make the devices more comfortable so that they can be used in industrial work settings without causing harm to the worker.

CHAPTER IV

THE IMPACT OF USING WEARABLE DEVICES ON THE OPERATOR DURING THE

"PUTTING" TASK

4.1   Introduction

Technological advancements that have occurred during the last twenty years have

provided considerable interest in improving the efficiency of warehousing operations (Kembro,

Danielsson, & Smajli, 2017). Currently, options are being explored to incorporate emerging

technology into existing work processes to improve efficiency and effectiveness (De Koster et

al., 2007). For example, rugged handheld devices have been transitioned into warehouses over

the past 20 years (Nair, Tsiopanos, Martin, & Marshall, 2018). These devices help keep track of

product movement from transmission through material handling and other parts of the

warehousing process (Burch, Strawderman, & Bullington, 2016; Burch, Strawderman, &

Carruth, 2016, Burch et al, 2017; Cannon, Strawderman, & Burch, 2015; Yao & Carlson, 1999).

The demand from customers to receive their orders quickly makes material handling

operations the most critical task in the supply chain (Kembro et al., 2017). The main tasks

involve receiving, storing, picking, and shipping of materials or products (Cirulis & Ginters,

2013). For instance, order picking is seen as the most labor-intensive task, is financially taxing

on companies (Stoltz et al., 2017), and accounts for over half of all costs in the warehouse

(Chabot, Lahyani, Coelho, & Renaud, 2017). A significant amount of research has been

conducted for order picking due to the need for fast-paced, error-free work (Stoltz et al., 2017).

Presently, the other warehousing tasks have not been researched as much because the cost of these tasks is considered to be not as demanding on companies (Davarzani & Norrman, 2015).

The receiving, shipping, and storing of products, also called the putting task, play a significant role in ensuring on-time deliveries. Therefore, other warehousing and logistical tasks should be researched in order to further improve upon managing the departure times of customer orders (Alonso-Ayuso, Tirado, & Udías, 2013). In order to complete the putting task in a distribution warehouse, workers are asked to load and unload items from delivery trucks, vans, airplanes, and ships (Cirulis & Ginters, 2013) utilizing asset tracking and management systems. This often requires workers to hold handheld devices while moving and scanning items or adding an additional process step of holstering then retrieving the scanner after each item movement. The incorporation of newer technology—such as wearable technology—is viewed as an option to help with sharing the workload, reducing fatigue, and aiding in the elimination of some processing decisions required by workers (Cirulis & Ginters, 2013).

Wearable technology is a growing topic of interest for research in industry (Syberfeldt et al., 2017) and is defined as a device that requires no human effort to keep the device attached to the body, remains in place regardless of physical movement, and can be interacted with without being removed (Knight et al., 2006). These devices are designed to be worn on various areas of the body based on need of the task being performed. The benefits that wearable devices offer have led` to the exploration of this technology for application in logistics operations (Kim et al., 2016). There is a void in current research regarding rugged handheld devices used in warehousing operations. The purpose of this study was to (a) compare productivity between a commonly used handheld form factor and two newer, wearable form factors when interrogating

60

barcodes during a putting task and (b) compare the participants' Comfort Rating Scale (CRS) and body discomfort scores while using the scanning solutions.

4.2   Literature Review

Manufacturing and retail companies are working to control the flow of information and materials while minimizing costs and providing good customer service. Many companies have already improved automation of supply chain processes by investing in innovative solutions such as inventory management tools (Sahin & Dallery, 2008). Automation of supply chain processes is of increasing importance as employees of larger industrial companies are required to handle massive sums of consumer goods and merchandise (Kudelska & Pawłowski, 2019). Suppliers ship products to distribution centers where they are received, placed in storage, and picked as part of orders (Goomas, 2010).

The use of computer technology in manufacturing and distribution centers has led to an increased need to investigate ways to improve real-time information systems used to track the location of products. Barcoding and interrogation technology helps to accurately manage inventory in warehouses and distribution centers in an efficient and economical way (Manthou & Vlachopoulou, 2001; Xu, Kamat, & Menassa, 2017). Barcode scanning is a meticulous task requiring workers to be near items while focusing their scanning device over the barcode in order to interrogate the information represented by barcoding structures. Rugged handheld scanners are a necessity for this process and one of the most common devices currently used by delivery service companies (Cannon et al., 2015). Handheld scanners were first implemented to replace the use of pencils, paper, and clipboards in order to increase productivity (Nair et al., 2018). However, scanner efficiency is limited to the technology embedded in the device that determines the method of reading barcodes (Xu et al., 2017). Previous research conducted focused on the

testing of new, ergonomic handheld scanners to eliminate some wrist tilting motions that were noticed while completing order picking tasks. This research found that there was a 14% productivity increase using the new handheld scanners and that elimination of these wrist motions positively impacted productivity (Nair et al., 2018). Data entry studies on handhelds have been performed as well where the data entry type (touchscreen versus physical keys) was evaluated both quantitatively (Burch et al., 2016; Cannon et al.,2015) and qualitatively. The research found that all rugged handheld users were 19% faster on a touch only interface and that, globally, there is still a preference for physical keys respectively.

Smart glasses technology has been identified as a tool that can support the task of assembly, maintenance, quality control, and material handling in the future (Syberfeldt et al., 2017). These wearable computers have mobile Internet connections and are worn like glasses or attached to existing eyewear to display information in the user's field of view (Rauschnabel, Brem, & Ivens, 2015). This portability allows operators to have their hands free while working (Syberfeldt et al., 2017). Initial studies conducted on the use of these devices explored the successful implementation of smart glasses in picking and assembly tasks (Paelke, 2014; Schwerdtfeger, Reif, Günthner, & Klinker, 2011). However, very few manufacturing companies have adopted them for use. Existing research has identified the lack of marketing, as well as the lack of standardization across the variety of designs, as reasons that companies have not implemented smart glasses in industry (Syberfeldt et al., 2017). The challenge is to create a device with weight evenly distributed in order to increase comfort for the user (Real, & Marcelino, 2011). In a recent study, user's comfort when wearing three different weighted pairs of smart glasses was assessed. The results from Chapter II revealed that participants experienced the least amount of comfort with glasses with weight placement on the side. Another study found

that objects such as batteries and storage devices on glasses type wearable devices should be placed near the neck pivot joint. In this study, when the weights were placed closer to the ears, these devices had a lower discomfort rating (Chang et al., 2018). In 2014, an application was created for Vuzix M100 smart glasses to allow for hands free scanning of QR and barcodes (Newswire, 2014). This application now provides new opportunities to study how using smart glasses can help with scanning barcodes located on packages, as well as items to assist in improving other warehousing operational tasks.

There is a void in current research on using wearable technology's scanning abilities to scan barcodes in distribution and warehousing facilities. An area that should be evaluated before the incorporation of this technology is the evaluation of the worker's ability to complete tasks without experiencing discomfort. This study will address the use of select scanning devices and smart glasses used in industry to perform a comparative analysis of comfort and discomfort scores, and level of productivity while completing a simulated putting task. The putting task will involve the loading and unloading of weighted boxes into a mock AMJ-style container built to specific freight truck and aircraft cargo dimensions. Comfort will be measured and compared against three devices, (a) Honeywell wand scanner, (b) Vuzix M100 smart glasses, and (c) Motorola RS507 ring scanner, using an averaged CRS score. A factor that must be monitored when measuring comfort is how comfort changes over time (Pearson, 2009). After each period of 20 minutes, the participants completed the CRS and Body Discomfort Scale to assess this comfort change.

The following hypotheses have been made concerning this study:

1.   The users will be more productive scanning and moving the boxes when using the ring scanner and smart glasses than the wand scanner.

2. Participants will be more uncomfortable when wearing smart glasses in comparison to ring scanners.

3. Participants will experience more discomfort when wearing smart glasses in comparison to ring scanners.

4.3 Methods

This experiment was designed for the putting processes used in warehousing and was conducted in a laboratory setting. The study was conducted in the Human Factors and Ergonomics lab at Mississippi State University.

4.3.1 Participants

Forty participants (age: 23.12 ± 5.73; gender: 20 female / 20 male; head circumference: 57.73 ± 3.90 cm) were recruited from Mississippi State University and the Starkville, Mississippi community. Fifteen percent of the participants were very familiar with material handling tasks while 47.5% were not familiar. Out of all the participants, 57.5% had experience with wearable technology such as Apple Watch, Fitbit, and virtual reality glasses. Participants received $10 per session with a bonus of $20 for completing all three sessions, for a total of $50.

4.3.2 Measures

4.3.2.1 Comfort Rating Scales

The participants were asked to evaluate the comfort of each device by using the Comfort Rating Scales (CRS) created by Knight and Baber (2005). Physical copies of the CRS survey was provided to study participants. They were asked to evaluate each of the six dimensions of comfort: Emotion, Attachment, Harm, Perceived Change, Movement, and Anxiety, when using each wearable device (e.g. ring scanner and smart glasses). The descriptions for the six measures

of comfort were modified slightly for the wand scanner since the device is not a wearable. Participants completed the CRS survey during the following times for each session: at the beginning of trial, after 20 minutes, after 40 minutes, and after 60 minutes when the trial was over. Average CRS scores and subscores were used for data analysis.

4.3.2.2 Body Discomfort Scale

Each participant was asked to evaluate their level of discomfort throughout each session using the provided body discomfort scale (Corlett & Bishop, 1976). A paper-based scale was provided to the participants which included an image of the body along with a table labeled with the following increments: no, minimal, mild, moderate, severe and extreme discomfort on a 6-point Likert scale. The participants were asked to complete the form before the session began and again after each period of twenty minutes (same as the CRS survey).

4.3.2.3 Post Survey

After the participants completed the putting task they were asked to complete a device perception survey for the wand scanner, ring scanner, and smart glasses. The questions asked participants if they would use the device if hired to complete a similar task, if they would be comfortable wearing the device for four to eight hours, and if they had other concerns about the device. After the third session the participants were also asked to identify which of the devices was the most and least comfortable with the option to provide more than one answer.

4.3.3 Materials

This study required the use of an Intermec/Honeywell SF61 wand scanner, a pair of Vuzix M100 smart glasses, and a Motorola RS507 ring scanner (*Figure 4.1*). These devices were used to simulate the scanning of packages while workers completed the putting task. Six

different standardized sizes of shipping boxes were used (***Table 4.1***). Box sizes were selected

from replicated volume data from AMJ containers at a large industrial company. Guglielmo

(2013) reported that 86% of the packages shipped by Amazon weighed five pounds or less. For

this study, old newspapers were added to each standardized box to achieve a weight between one

and five pounds. A 20% distribution rate for each weight was used to ensure standardization of

this randomized process. For example, for each box size, twenty percent of the total box count

weighed one pound, twenty percent weighed two pounds, etc. Other materials utilized were

barcode labels, timers, and a wall charger to ensure that the glasses were properly charged during

the session.

Figure 4.1   Devices used for Study

a) Image of the Intermec/Honeywell SF61 wand scanner; (b) Image of the Motorola RS507 ring scanner; (c) Image of Vuzix M100 smart glasses

Table 4.1   Total Number of Boxes used by Size

Box Dimensions	Total of Boxes
20 x 20 x 16	15
10 x 10 x 10	101
8 x 8 x 8	47
18 x 12 x 12	72
6 x 6 x 20	25
26 x 6 x 20	10

List of the six dimensions of boxes and total used for each.

4.3.4   Procedure

The experiment was reviewed and approved by the Mississippi State University Institutional Review Board (IRB). The protocol consisted of a total of three sessions where each equipment type was used for a single session. A wand scanner, a ring scanner and a pair of smart glasses were each used to complete a simulated scanning and putting task. The simulated work consisted of using the provided scanning device to scan and move boxes into and out of a mock AMJ cargo container. All the packages used in this study weighed between one and five pounds. Participants were not allowed to complete more than one session per day.

Participants reported to the Human Factors and Ergonomic lab, reviewed and signed an informed consent form, completed a demographic survey, were given information about the task, and were provided with a device and a box to practice scanning. The participants practiced scanning boxes for three minutes or until a level of confidence was established prior to starting the task. The wand scanner was used for the first session for all participants as the control,

baseline device. The final two sessions counter-balanced the smart glasses and ring scanner to eliminate any order effect.

The three sessions consisted of each participant completing the scanning and putting tasks while using each device for an hour. During each session, the participants were asked to complete the CRS and Body Discomfort Scale, as described previously. The time to complete the surveys did not count toward the total task time. At the end of the session, participants were also provided with a post survey to complete.

The participants were asked to simulate the correct scanning technique for each device (*Figure 4.2*). Before providing the participants with a pair of Vuzix glasses, the researcher turned the glasses on to the scanning application. The scanning application was previously downloaded onto the smart glasses and was used to read embedded barcode data. The researcher then placed the lens on the right side of the glasses frame. For the wand and ring scanner, participants were asked to press the scan button to interrogate the barcode labels on the box. Each device provided auditory and visual feedback to the user when the labels were properly scanned (*Figure 4.3*).
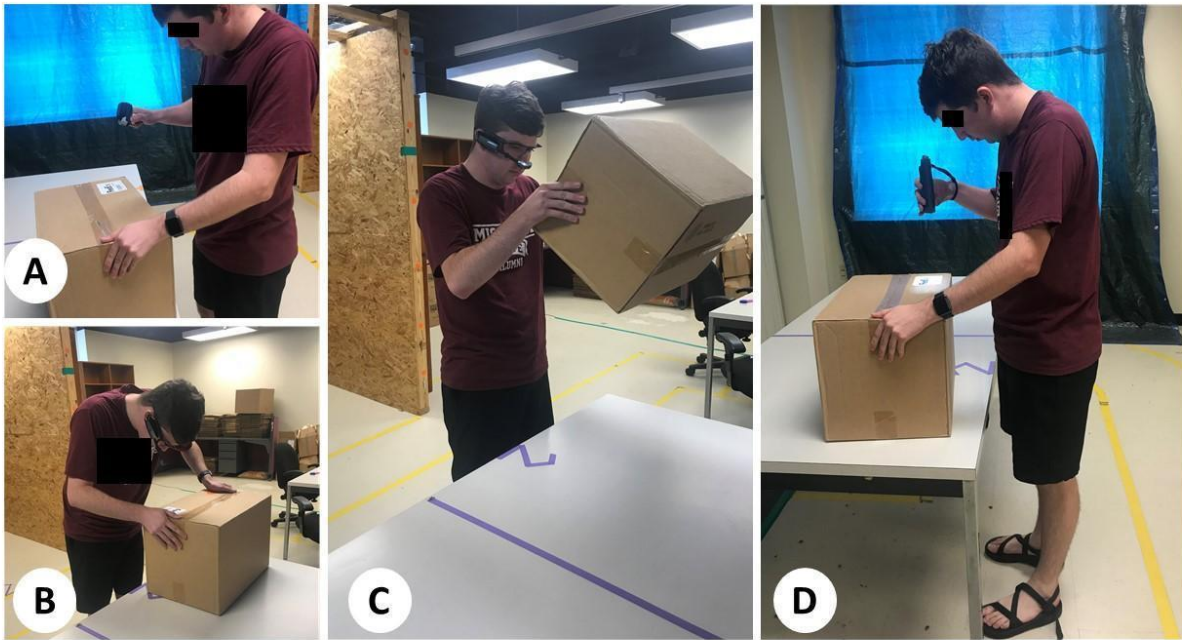
Figure 4.2   Demonstration of Scanning Barcode with the Devices

A visual representation of how to use the device to scan the barcode. (a) Scanning barcode with ring scanner. (b) & (c) Scanning barcode with glasses (demonstrating scanning options by bending over or picking up the box). (d) Holding wand in hand and pressing scan button with thumb.
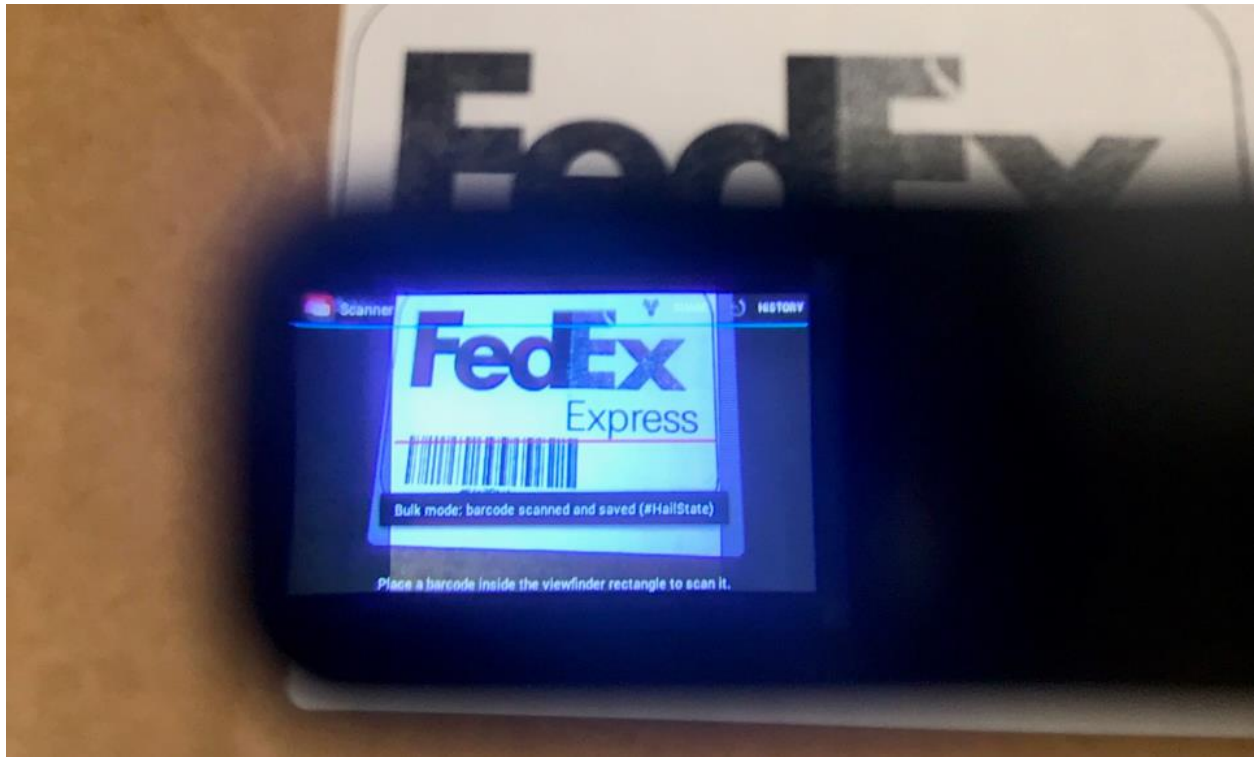
Figure 4.3   Visual of Feedback from Glasses

A visual of what the users saw when scanning the barcode on one of the boxes. The feedback after a successful scan was a beep along with visual feedback "Bulk mode: barcode scanned and saved (#HailState)".

4.3.4.1   Putting Task

This research utilized an AMJ-style container built to specific freight truck and aircraft cargo dimensions. This container was designed to fit the upper belly contour of a large aircraft. For this study, 270 boxes were prepared for use. At the beginning of each participant trial, boxes were stacked on one side of the container, while the other half of the container remained empty (*Figure 4.4*).

Figure 4.4   Set up of Putting Task

Initial set-up of boxes in AMJ-style container.

Participants were asked to scan and move one box at a time. They began by taking and scanning a box at the table, placing the box in the empty half of the AMJ-style container, bringing back one box from the full side of the AMJ, and then scanning the package and placing it back on the table. (*Figure 4.5*). This process would then repeat for the entire hour for every participant session. This process flow allowed for the capture of productivity from both sides of package movement both into and out of a ULD (unit load container). After periods of 20 minutes, the participants paused to complete the CRS and Body Discomfort Scale forms. When the forms were completed, participants were asked to continue the assigned tasks. This process was repeated until time was up on the hour-long session. Before the start of the trial and at the end of the hour, each participant completed the CRS and Body Discomfort Scale forms meaning

that for every participant session, these two forms were completed four times each. Over the

course of the three hour-long trials, each participant completed these forms a total of 12 times

and four times per device type.
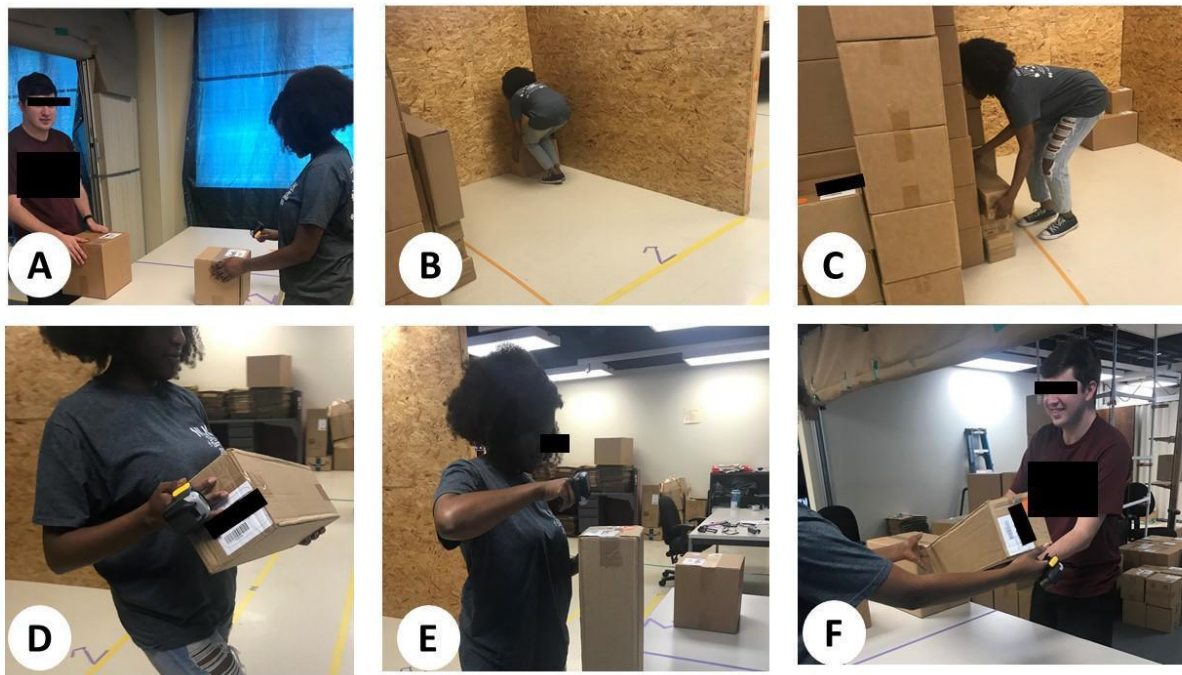
Figure 4.5   Demonstration of Putting Task

A researcher demonstrating a visual representation of the key components of the participant
session process flow in order to complete the putting task while using a ring scanner formfactor:
(a) receiving the box and scanning barcode, (b) placing box in the empty half of the AMJ, (c)
Picking up box from the full side of the AMJ, (d) carrying the box back to table, (e) scanning
box, and (f) returning box to researcher in order to receive another and begin the process over
again.

4.3.5   Statistical Analysis

Productivity and comfort are the two dependent variables that were measured during this

study. For this study, productivity was defined as the number of boxes scanned and moved

during each session. The data collected was analyzed using SPSS and Microsoft Excel. The data

collected was described using means and standard deviations. Comfort was analyzed using a weighted system that was created in a previous study. Repeated-measures analysis was used to identify the main and interaction effects between productivity, comfort, and discomfort by device, task, and gender.

4.4   Results

The participants were asked to identify the most and least comfortable device used after completing all three sessions. The participants were given the option to select more than one answer. The ring scanner was considered the most comfortable device and smart glasses was considered the least comfortable device (***Figure 4.6***).
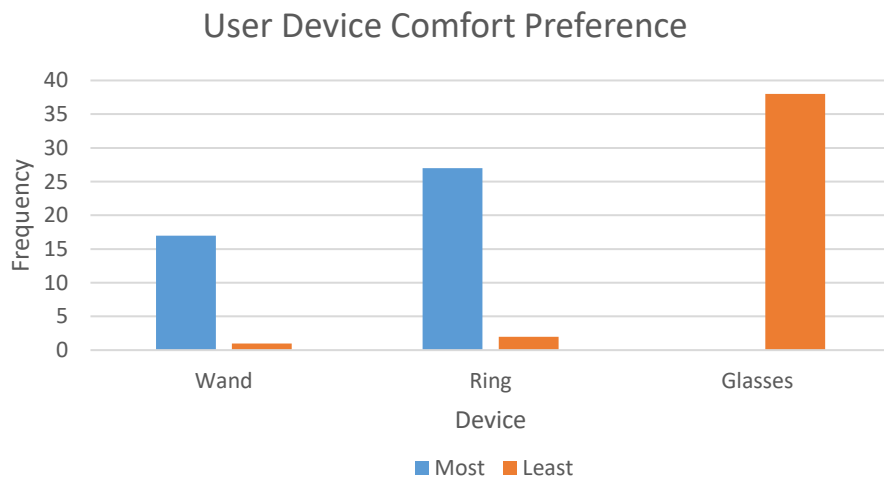
Figure 4.6   User Device Comfort Preference

Reports the results from the participants identifying the most and least comfortable device.

After completing the task with the wand scanner, ring scanner and smart glasses, participants were asked would they be comfortable using the provided device in the workplace. In response to this question, 75% of participants reported they would feel comfortable using the

wand scanner, and 85% answered affirmatively to using the ring scanner. However, only 7% of participants reported they would feel comfortable using a pair of smart glasses if hired for a job in which this task would be performed. Participants were also asked if they would be comfortable using each device for a four to eight-hour shift. Sixty three percent of participants said they would be comfortable using the wand scanner, and 73% reported being comfortable using the ring scanner for the shift. In contrast, 13% of participants responded that they would be comfortable using the glasses. Regarding the low approval rate of smart glasses, participants were concerned about the glasses slipping off and restricting their vision (*Figure 4.7*).
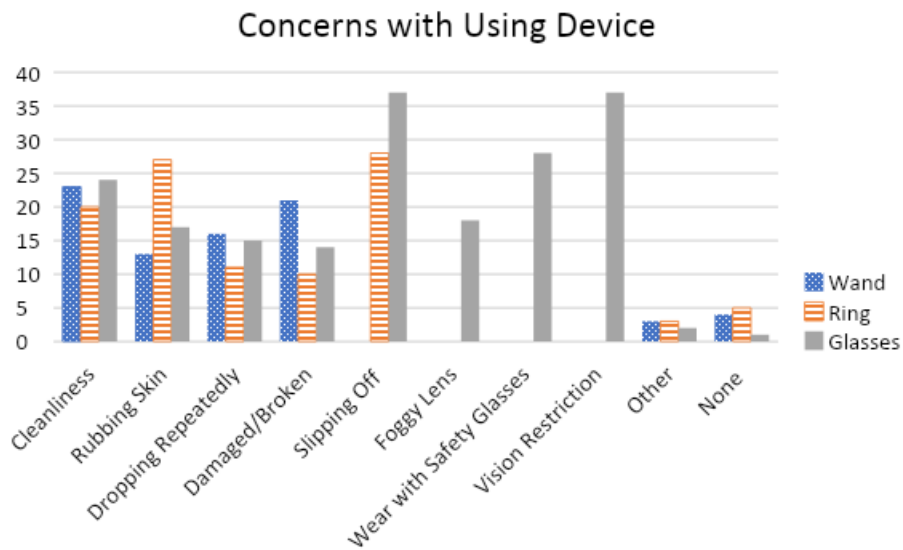
Figure 4.7   Concerns with Using Device

Concerns that participants had about using each device type at work.

4.4.1   Productivity

Table 4.2 reports the descriptive statistics for the total number of boxes moved during each session by device and gender. *Table 4.3* shows descriptive statistics for time-per-box by

device and gender. The sample size represents the number of data points analyzed instead of number of participants.

The results from a repeated measures ANOVA indicated a significant effect for device, $F(1.553, 60.578) = 247.7333$, $p < 0.001$. Productivity, defined as the number of boxes scanned and moved, was the highest for the ring scanner, followed by the wand scanner. The smart glasses had the lowest productivity. Gender was not found significantly affect productivity, $F(1,118) = 0.387$, $p = 0.535$.

Table 4.2   Descriptive Statistics

	N	Min	Max	Mean	SD
Overall	120	91	645	361.78	130.44
Device ($F(2,117) = 110.107$, $p < 0.001$)					
Wand	40	268	603	413.68***	74.29
Ring	40	277	645	456.28***	94.80
Glasses	40	91	362	215.38***	59.22
Gender ($F(1,118) = 0.387$, $p = 0.535$)					
Male	60	91	645	369.20	140.29
Female	60	132	622	354.35	120.52
	* $p < .05$, ** $p < .01$, *** $p < .001$				

Descriptive Statistics of the productivity during each session.

Table 4.3   Descriptive Statistics

	N	Min	Max	Mean	SD
Overall	120	0.093	0.659	0.196	.095
Device (F(1.553, 60.578) = 247.7333, $p < 0.001$)					
Wand	40	0.100	0.224	0.150**	0.028
Ring	40	0.093	0.217	0.138**	0.031
Glasses	40	0.166	0.659	0.301***	0.092
Gender (F(1.083,41.148) = 0.844, $p = 0.372$)					
Male	60	0.093	0.659	0.185	0.103
Female	60	0.113	0.455	0.207	0.085
* $p < .05$, ** $p < .01$, *** $p < .001$					

Descriptive Statistics of time per box (minutes).

4.4.2   Comfort

Table 4.4 reports mean and standard deviation of CRS subscale scores The results from the repeated measures ANOVA of the CRS scores reported that Emotion (F(1.614, 62.938) = 16.238, $p < 0.001$), Attachment (F(2, 78) = 24.393, $p < 0.001$), Harm (F(2, 78) = 9.060, $p < 0.001$), Perceived Change (F(1.801, 58.854) = 9.060, $p < 0.001$), Movement (F(1.650,64.347) = 19.229, $p < 0.001$) and Anxiety (F(1.563,60.947) = 26.448, $p < 0.001$) were significantly impacted by device type. Participants reported higher Emotion scores when wearing the glasses (M = 3.725) in comparison to using the wand (M = 0.750) and ring scanner (M = 1.188). Participants reported higher Attachment scores when using the glasses (M = 7.800) in comparison to the wand (M = 2.950) and ring scanner (M = 4.363). Participants reported higher Harm scores when using the glasses (M = 3.463) in comparison to when using the wand (M =

76

1.325) and ring scanner (M = 1.525). Participants reported higher Perceived Change scores when wearing the glasses (M = 6.800) in comparison to the wand (M = 1.588) and ring scanner (M = 2.413). Participants reported higher Movement scores when wearing the glasses (M = 5.850) in comparison to using the wand (M = 2.388) and ring scanner (M = 2.438). The participants reported higher Anxiety scores when using the glasses (M = 4.438) in comparison to using the ring (M = 0.713) and wand scanner (M = 1.525). There was no significant main effect for independent CRS scores and gender. There was no significant two-way interaction between device and each independent CRS score.

Table 4.4   Reports mean and standard deviation of CRS subscale scores

	CRS Subscale					
Scenario	E	Att	H	PC	M	An
Wand Scanner	0.750(1.621)	2.950(3.397)	1.325(1.697)	1.588(2.367)	2.388(3.426)	0.712(1.235)
Ring Scanner	1.188(2.954)	4.363(4.594)	1.525(2.9044)	2.413(3.5786)	2.438(4.027)	1.425(3.337)
Smart Glasses	3.725(4.817)	7.800(4.735)	3.463(4.336)	6.800(5.394)	5.850(5.129)	4.438(4.713)

Reports mean and standard deviation of CRS subscale scores. All of the subscales were significantly impacted by device type. Note: E = Emotion; Att = Attachment; H = Harm; PC = Perceived Change; M = Movement; An = Anxiety

The results from the repeated measures results show that there was a significant difference between devices in average comfort scores (F (1.709, 66.644) = 40.565, $p < 0.001$). Participants were more uncomfortable using the glasses (M = 5.346) than using the wand (M = 1.619) and ring scanner (M = 2.226). *Figure 4.8* is a visual representation of how comfort was affected over time. Comfort when using smart glasses produced a statistically significant change based on time (F(1.505, 58.684) = 33.596, $p < 0.001$). The mean comfort scores based on time

did not lead to any statistical significance for the wand and ring scanner. Participants reported

being more uncomfortable using the glasses in comparison to the wand and ring scanner.
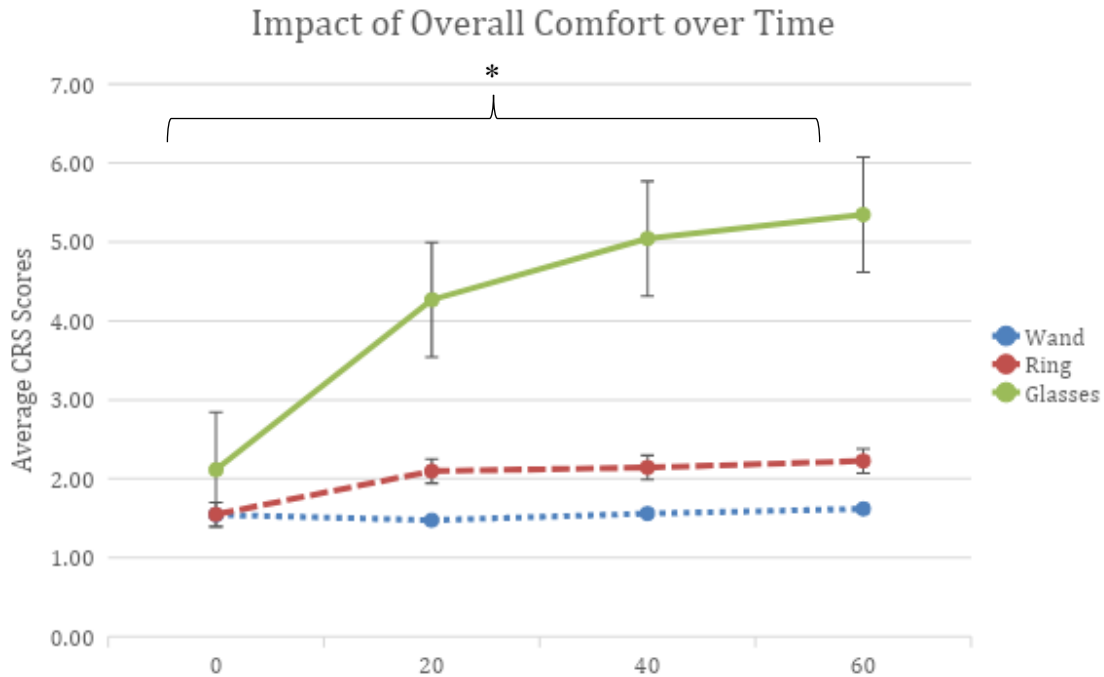
Figure 4.8   Impact of Overall Comfort over Time

Shows the average CRS scores over time for each device. There was a significant increase in comfort scores over time for the glasses. (* represents significant difference between comfort over time for the glasses and bars represent standard errors)

4.4.3   Discomfort

Table 4.5 reports mean and standard deviation of Body Discomfort subscale scores. The

results from the repeated measures show that discomfort of the eye ($F_{(1.177, 45.898)} = 46.433$, $p

< 0.001$), neck ($F_{(1.312, 51.187)} = 21.263$, $p < 0.001$), shoulder ($F_{(2, 78)} = 3.772$, $p = 0.027$),

upper back ($F_{(2,78)} = 3.641$, $p = 0.031$), elbow ($F_{(1.360, 53.053)} = 3.740$, $p = 0.046$) and wrist

($F_{(2,78)} = 8.273$, $p = 0.001$) was significantly affected by device type. Participants experienced

more eye discomfort when using the smart glasses (M = 2.600) than with the wand (M = 1.225)

and ring scanner (M = 1.125). Participants experienced more neck discomfort while using the

78

smart glasses (M = 2.325) than with the wand (M = 1.500) and ring scanner (M = 1.325).

Participants experienced more discomfort in the upper back when using the glasses (M = 1.725)

in comparison to the ring scanner (M = 1.350). Participants experienced more discomfort in their

wrist/hand when using the wand (M = 2.075) and ring scanner (M = 1.900) in comparison to the

smart glasses (M = 1.375).

Table 4.5   Body Discomfort Subscales Reported Means and Standard Deviations

Device	Body Discomfort Subscales											
	Eye	Neck	S	UB	Elb	LB	Arm	W/H	Th	Knee	CofL	F/A
Wand	1.23(0.62)	1.50(0.78)	1.60(0.87)	1.63(0.90)	1.38(0.93)	1.75(1.06)	1.65(0.98)	2.07(1.02)	1.33(0.88)	1.20(0.79)	1.23(0.73)	1.38(0.98)
Ring	1.13(0.65)	1.33(0.76)	1.43(0.90)	1.35(0.86)	1.15(0.662)	1.55(1.09)	1.45(0.93)	1.90(1.15)	1.15(0.58)	1.15(0.66)	1.18(0.71)	1.30(0.94)
Glasses	2.60(1.37)	2.32(1.31)	1.75(1.03)	1.73(1.04)	1.13(0.52)	1.73(1.13)	1.50(0.91)	1.38(0.67)	1.22(0.73)	1.18(0.71)	1.17(0.59)	1.38(1.01)

Reports mean and standard deviation of Body Discomfort subscale scores. Discomfort of the eye, neck, shoulder, upper back, elbow, and wrist/hand were all significantly impacted by device type. Note: S = shoulder, UB = upper back, Elb = elbow, LB = lower back, W/H = wrist/hand, Th = thigh, CofL = calf of leg, F/A = foot/ankle

An average score was calculated for body discomfort to look at discomfort over time (*Figure 4.9*). Using each device caused the participant discomfort. However, participants experienced more discomfort overall when using the glasses and experienced the least amount of discomfort when using the ring scanner. The results from the repeated measures show that there was a significant difference in discomfort by device type ($F(1.778, 69.354) = 10.288$, $p < 0.001$) and time ($F(1.110, 43.281) = 18.626$, $p < 0.001$). There was no significant difference in discomfort based on gender ($F(1,38) = 0.096$, $p = 0.758$). There was no two-way interaction for device type and gender $F(1.736, 65.975) = 2.384$, $p = 0.107$ and time and gender $F(1.108, 42.095) = 0.035$, $p = 0.874$. There was a significant two-way interaction for discomfort based on device type and time $F(3.808, 148.514) = 6.410$, $p < 0.001$. Participants reported more discomfort using the wand scanner after 40 and 60 minutes than when they started. Before using the ring scanner the participants experienced significantly less discomfort after 60 minutes of use. Participants felt more discomfort with the smart glasses after 20, 40, and 60 minutes of use as compared to when they began the session. Overall, participants experienced the most discomfort with the smart glasses; the longer participants wore the smart glasses, the more discomfort they felt over time.
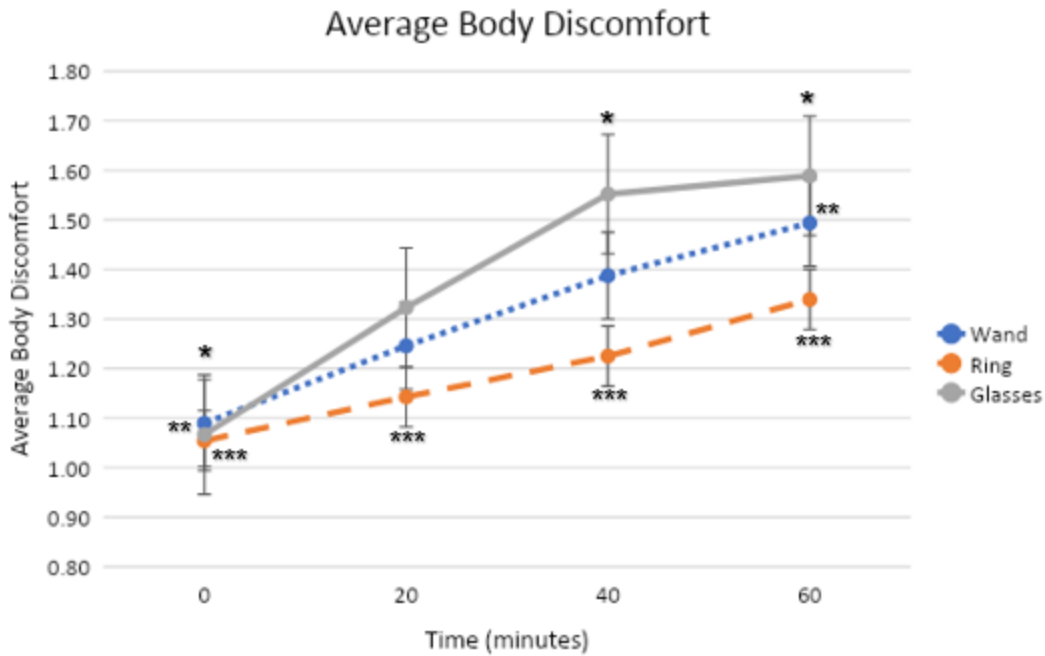
Figure 4.9   Average Body Discomfort

Visual representation of the discomfort experienced with each device during the task.
(significance in discomfort over time represented by * for glasses, ** for wand, and *** for ring
and bars represent standard errors)

4.5   Discussion

The purpose of this study was to assess user comfort for three devices when completing

the putting task. The use of smart glasses to scan the barcodes on boxes were the most

uncomfortable and caused the most discomfort. The participants preferred using the ring and

wand scanner to complete the putting task.

Overall, the smart glasses generated the highest CRS scores across the comfort

dimensions concluding that the participants were uncomfortable wearing the glasses. The high

Attachment and Perceived Change scores indicate that the uneven weight distribution of the

82

glasses caused the users to feel the device on their body and to feel physically different. The Movement scores validate their concerns about the device slipping off their face requiring the user to adjust how they moved. The high Anxiety and Emotion scores may be associated with the challenges that occurred when trying to scan the barcode. Also, while using the glasses the participants experienced eye, neck, and upper back discomfort.

The ring and wand scanner had relatively similar results. Attachment scored the highest amongst all the CRS dimensions for both devices. The ring scanner is a compacted scanning device that sits on two fingers that is a very physically noticeable change. This explains the relatively higher score in comparison to holding the wand scanner. The other dimensions, Emotion, Harm, Perceived Change, Movement and Anxiety had relatively low scores indicating that the device was comfortable to use. The participants did experience some hand/wrist discomfort while completing the task.

The focus of implementing wearable technology is to improve the operations process specifically looking at order processing speeds and process quality (Reif & Walch, 2008). The use of wearable devices offers a hands-free solution to allow users to be more flexible (Stoltz et al., 2017). In previous research, attributes that are important for the adoption of smart glasses are functionality, battery life, compatibility, and form factor (Adapa et al., 2018). In Chapter II, participant survey data indicated smart glasses were uncomfortable due to the battery overheating and requiring constant adjusting. During this study, overtime users experienced discomfort while wearing the glasses, which agrees with Brusie et. al. (2015) findings that long-term wear of smart glasses can lead to discomfort. The results from this study will help employees and employers see from a comfort and productivity perspective how implementing

wearable technology into their company can assist with having a more efficient and productive company.

4.6   Conclusion

The results of this study emphasize the benefit in using wearable devices as a tool to assist in material handling tasks. Based on these findings, it is recommended that companies continue to use the ring or wand scanner. The performance when using these devices was significantly better than using the glasses in terms of productivity, comfort, and discomfort. The ring and wand scanner are simple scanning device options that provide instant and effective feedback to the user.

Further development of smart glasses is needed before they can be fully implemented in logistics tasks. While participants were still productive when using the smart glasses, more information is needed concerning the impact of comfort and discomfort of using this device on the user during a full days work. Companies considering utilizing smart glasses to improve productivity can use the results of this study to identify key characteristics needed to better optimize this type of wearable device.

4.6.1   Limitations

This study found that participant productivity was decreased when using the glasses. The scanning application used for this study required that participants do excessive bending or bring the box close to the eye in order to scan the barcode. Also, the app was continuously running causing the device to overheat and drain the battery. The research team had three pairs of smart glasses available and could swap the devices out every 20 minutes, if needed, while the participants completed the CRS and Body Discomfort Scale. These issues with the smart glasses

could have frustrated participants and interfered with overall productivity. There were no limitations identified for the wand and ring scanner. More research is needed to better understand how smart glasses can improve the package handling process. This study only used one type of smart glasses so this study could be replicated to test other smart glasses that could potentially be a better option for companies.

CHAPTER V

CONCLUSION OF DISSERTATION

These three studies have identified comfort as an important factor that should be considered when contemplating using wearable devices in the industry. The studies offered meaningful insight from a comfort perspective for industry officials attempting to incorporate wearable technology in the work place. The primary purpose of this research was to understand how using wearable devices is impacted by comfort. Furthermore, this research attempted to identify how comfort impacts productivity when completing logistics tasks in an investigational environment.

The first study identified more research needs to be conducted in order to understand how companies can alter wearable devices without causing their workers to be uncomfortable. The participants thought the weighted side set up was the most comfortable, but their CRS scores indicated they were still uncomfortable using the devices. Even with varying the location of the weight, participants were able to complete a similar amount of pick lists and transported approximately the same number of boxes for each case. However, participants responded that they felt wearing the glasses hindered their performance. Participants also reported that they did not like wearing smart glasses during the picking or putting tasks. Therefore, companies considering making an investment into smart glasses to improve productivity should consider other alternatives to increase memory and extend battery life instead of adding more weight to the frame of these devices.

The second study attempted to improve the CRS by creating a weighted comfort score. The addition of the weights was found to be ineffective since important factors of comfort was not reflective in the score. As a result, it validated the CRS was still useful even though technology has advanced since its creation. The findings reveal there is also value in measuring the perception of comfort without completing the task. While results may differ due to experience, the information provided may assist in the enhancement of wearable devices.

The final study was designed to use the scanning functions of two wearable devices and a handheld wand scanner to examine how comfort would impact productivity. Participants were more productive using the ring and wand scanner than the smart glasses. Data established that participants were more uncomfortable using the smart glasses and experienced discomfort in the eye, neck and shoulder. It is recommended that companies continue to use the ring and wand scanner. More research needs to be conducted to improve smart glasses before considering them as an alternative tool for the ring and wand scanner.

Participants were not fond of using the smart glasses in study one and three. In the first study the addition and placement of the weights impacted user comfort. For the third study having to bring the box near the face to scan the box made the participants uncomfortable. This research has shown that there is a need for additional improvement with smart glasses before incorporating this technology into the work place. Future research should investigate if the addition of a strap to the glasses would provide users a since of security that would lower the scores for Movement and Anxiety. Companies contemplating incorporating smart glasses to improve productivity can use the results of this study to identify important features needed to optimize this wearable device.

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APPENDIX A

STUDY 2 SENARIOS AND INSTRUCTIONS

Please read the following scenario of a person being asked to complete a task while using a wearable computer device. Wearable technology can be used while being attached or fitted to your body.

Scenario 1

You have recently started working as a full-time order picker at Kroger. Kroger has decided to test out a ring scanner in place of their standard handheld scanners. Your job is to pick inventory off the shelves to complete customers' pickup orders by scanning items with a ring scanner and placing them into a bag. Both hands will remain free for picking items. You are scheduled to complete this job for 8 hours with an hour break for lunch and two fifteen-minute breaks, one in the morning and another in the afternoon. The ring scanner weighs about 5 ounces which is equivalent to the weight of a baseball.

Since Kroger leadership is evaluating the use of this new device, you will also have to report to your manager your experience from a comfort perspective. There are six factors you will use to assess comfort of this device: emotion (concerns with appearance), attachment (feeling the device physically on the body), harm (damage to body), perceived change (feeling different), movement (affects user movement), and anxiety (worrying about device, safety, and reliability).

Please read the following scenario of a person being asked to complete a task while using a wearable computer device. Wearable technology can be used while being attached or fitted to your body.

Scenario 2

You are an aircraft repair mechanic who is being trained by an engineer on how to repair different parts of an airplane. The engineer has provided you with a pair of smart glasses. The glasses provide you with step-by-step instructions on miniature screen, that will be placed in front of your dominant eye. You will be able to see the work in front of you, along with electronic instructions presented within your peripheral view, all while keeping your hands free. As aircraft repair mechanic, you work 8 hour shifts with an hour lunch break and two fifteen-minute breaks, one in the morning and another in the afternoon. Your pair of Vuzix glasses weighs about 13.1 ounces, which as a reference is about the weight of an unopened can of soda.

The engineer has asked that you report to your experience from a comfort perspective of how you like using this device. There are six factors you will use to assess comfort of this device: emotion (concerns with appearance), attachment (feeling the device physically on the body), harm (damage to body), perceived change (feeling different), movement (affects user movement), and anxiety (worrying about device, safety, and reliability).

Comfort Rating Scale (CRS; Knight & Baber, 2005)

Instructions: For each scale, move the slider and place it where it best indicates your perceived experience with the device.

Title	Endpoints	Description
Emotion	Low/High	I am worried about how I look when I wear this device. I feel tense or on edge because I am wearing the device.
Attachment	Low/High	I can feel the device on my body. I can feel the device moving.
Harm	Low/High	The device is causing me some harm. The device is painful to wear.
Perceived change	Low/High	Wearing the device makes me feel physically different. I feel strange wearing the device.
Movement	Low/High	The device affects the way I move. The device inhibits or restricts my movement.
Anxiety	Low/High	I do not feel secure wearing the device.

Emotion

Low   High

Attachment

Low   High

Harm

Low   High

Perceived change

Low   High

Movement

Low   High

Anxiety

Low   High
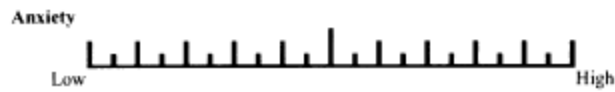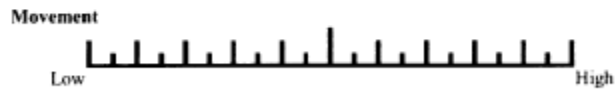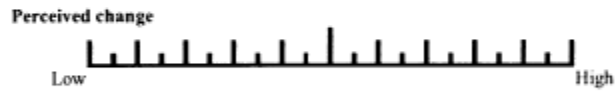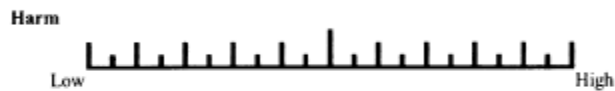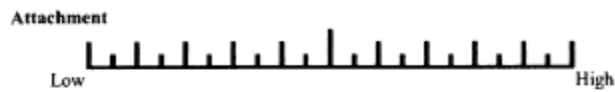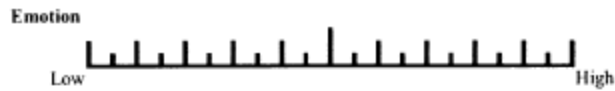
Please compare the following statements and pick the one that is most important to you. For A compared to B please choose A. (*Example: if Emotion is more important than Anxiety, you would select Emotion.*)

Emotion or Attachment	Attachment or Anxiety
Emotion or Harm	Harm or Perceived Change
Emotion or Perceived Change	Harm or Movement
Emotion or Movement	Harm or Anxiety
Emotion or Anxiety	Perceived Change or Movement
Attachment or Harm	Perceived Change or Anxiety
Attachment or Perceived Change	Movement or Anxiety
Attachment or Movement	A or B

1. While completing this task, which of the following answer choices would be the most concerned about when wearing the ring scanner/smart glasses:
a. Emotion (concerns with appearance)
b. Attachment (feeling the device physically on the body)
c. Harm (damage to body)
d. Perceived Change (feeling different)
e. Movement (affects user movement)
f. Anxiety (worrying about device, safety, and reliability)

2. When completing this task which of these dimensions would you consider to be the least important to consider for the ring scanner/smart glasses:
a. Emotion (concerns with appearance)
b. Attachment (feeling the device physically on the body)
c. Harm (damage to body)
d. Perceived Change (feeling different)
e. Movement (affects user movement)
f. Anxiety (worrying about device, safety, and reliability)

1. How old are you?

2. Gender
   a. Male
   b. Female
   c. Other _____

Wearable Technology

Google Glass   Apple Watch   Heart Rate Sensor

3. Wearable technology can be used while being attached or fitted to your body. Have you had experience with wearable technology?

   a. Yes (if yes, Questions 5, 7, 9,10,11 will appear)
   b. No

Personal Protective Equipment

Safety Goggles   Safety Hat   Safety Gloves

4. Personal Protective Equipment is clothing that's worn to provide protection to the user while working with dangerous tools or in a hazardous work setting. Have you had experience with personal protective equipment?
   a. Yes (if yes, Questions 6, 8, 12 will appear)
   b. No

5. I wear wearable technology on my……. (Select all that apply)
   a. Head
   b. Face
   c. Waist
   d. Arm
   e. Wrist
   f. Ankle

g. Other _____

6. I wear personal protective equipment on my…… (Select all that apply)
    a. Head
    b. Face
    c. Waist
    d. Arm
    e. Wrist
    f. Hands
    g. Ankle
    h. Other _____

7. On average, how many hours a day do you spend using wearable technology?
    a. Less than 1 hour
    b. 1-2 hours
    c. 2-4 hours
    d. 4-6 hours
    e. 6-8 hours
    f. More than 8 hours

8. On average, how many hours a day do you spend using personal protective equipment?
    a. Less than 1 hour
    b. 1-2 hours
    c. 2-4 hours
    d. 4-6 hours
    e. 6-8 hours
    f. More than 8 hours

9. When have you worn/used wearable technology? (Select all that apply)
    a. At Work
    b. At School
    c. At Home
    d. While Exercising
    e. Other_____

10. When have you worn/used personal protective equipment?
    a. At Work
    b. At School
    c. While Exercising
    d. Other_____

11. Why do you use wearable technology? (Select all that apply)
    a. Because it is required for my job
    b. Because it is entertaining
    c. Because everyone has one
    d. Because I want to track my heart rate/activities

e. Others_____

12. While wearing wearable technology they can be uncomfortable on my: (Select all that apply)
    a. Ear
    b. Nose
    c. Wrist
    d. Waist
    e. Chest
    f. Arm
    g. Ankle
    h. Other_____
    i. They are comfortable
    j. None of the above

13. While wearing personal protective equipment they can be uncomfortable on my: (Select all that apply)
    a. Ear
    b. Nose
    c. Wrist
    d. Waist
    e. Chest
    f. Arm
    g. Ankle
    h. Other_____
    i. They are comfortable
    j. None of the above

Thank you for taking the time to complete this survey.