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Women and Exoskeletons: Design and its Effect on Fit and Comfort

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Abstract: Exoskeletons are increasingly being used in industries as their benefits become known and they become more widely available. Although some exosuits are “one size fits most”, most exoskeletons come in a variety of sizes to match many worker sizes. However, sizing is only one element of fit. Other factors to consider include placement of the various exoskeleton components. With respect to female employees, back support exoskeletons often have chest pads that may not be comfortable and proportions between shoulder width, torso length and hip width may be more suited towards men. The purpose of this paper is to explore the design of currently available back and shoulder support exoskeletons to determine how well they may fit a female workforce. This paper will examine the jobs in which most injuries with women occur and then explore the possibilities that exoskeletons could provide in reducing the risk for musculoskeletal injury. Fields being examined include medical, manufacturing, construction, office, and retail. The purpose of studying women in exoskeletons is to bridge the gap between unisex suits built with men in mind, and truly unisex designs that are adjustable in more than just one aspect. Benefits of this type of study would be less injuries in the field, a larger exoskeleton market, customizable options, and opportunity to be utilized in more industries. Suggestions will be made with respect to better design elements that could lead to more exoskeleton utilization by women.

Keywords: Women, Exoskeletons

1. Introduction

Women make up the majority of employees as teachers, registered nurses, secretaries or administrative assistants, and nursing, psychiatric, and home health aides (Bureau of Labor Statistics, 2015). Additionally, women make up 9.9% of construction workers, 29.2% of manufacturing workers, 45.8% of public administration positions, and 44.7% of employees in the retail field (Bureau of Labor Statistics, 2018). Most of the time, women find themselves in less physically demanding jobs, except for the healthcare field. Exoskeletons may provide a way to support female employees and allow for companies to have a larger employee pool from which to recruit. While exoskeletons are useful in many areas, there seem to be none specifically designed with women in mind. This paper explores the gap between women and unisex exoskeletons.

An exoskeleton is a wearable technology that assists the wearer in performing tasks related to their job (Burris, 2018). Exoskeletons are often used to prevent musculoskeletal injuries which are prominent in fields like construction or manufacturing (Burris, 2018). Different types of exoskeletons exist, but torso support and back support suits will be the focus of this paper. These types help elevate stress and strain caused by performing tasks overhead that require heavy tools or keeping arms above the head for extended periods of time (Burris, 2018). Exoskeletons are being developed to help people improve existing skills and are going from bulky versions to sleeker designs (Wakefield, 2018). While exoskeletons can reduce fatigue, they are not meant to help people work longer hours. Working longer with assistance would keep employees

from getting physically tired, but not mentally tired; another issue that arises when discussing exoskeletons and their disadvantages (Wakefield, 2018).

There are always injuries in industry; even the most careful and safe employees can have an accident happen to them at some point. In 2016, 104,000,000 hours were lost on the production floor due to worker injuries in all industries; that means someone is injured every seven seconds (National Safety Council, 2019). Some of the injuries that keep employees from working are things that could be prevented with the use of exoskeletons. Overexertion made up 34% of injuries and contact with objects/equipment made up 25% of injuries in 2016 (National Safety Council, 2019). Over $25 billion has been spent in workers compensation payouts (Insurance Journal, 2015). Many workers compensation costs were related to overexertion at 25.3%, falls on the same level at 15.4%, being struck by equipment or an object at 8.9%, and falls to a different level 8.6% (Insurance Journal, 2015). Injuries, time off, and deaths cost the economy and industry more than just money. Turnovers, training, and a constant stream of employees in and out of companies can cause large losses.

2. Literature Review

2.1 Female Musculoskeletal Disorders

Musculoskeletal disorders affect the movement of the human body (Middlesworth, M., & Middlesworth, M. M., 2018). They can have multiple names and causes, like repetitive motion or stress, overuse, or ergonomic injury. There are many factors to be considered when discussing what parts of the body are affected by musculoskeletal disorders, including ligaments, tendons, muscles, etc. (Middlesworth, M., & Middlesworth, M. M. 2018). Women suffer from these disorders at an increased rate compared to their male counterparts (Industrial Safety and Hygiene News, 2004). Many of the musculoskeletal disorders that affect women take place in the wrist, neck, upper back, and shoulders; these can be caused by long hours of work, as well as tools and workstations that are not designed with women employees in mind (Industrial Safety and Hygiene News, 2004). The common musculoskeletal disorders that affect women most often are caused by their physiological and anatomical differences from men.

For starters, women on average live longer than men and often suffer from osteoarthritis and osteoporosis (McClure, et. al, 2005). Women experience osteoporosis up to four times more than men, 30% of women will have the disease at any given time, and half of women may experience a fracture of the hip, wrist, or vertebrae in their lifetime (McClure, et. al, 2005). Women are also more likely to have knee problems like problems with the ACL and joints of the knee. The knee holds most of the body weight when walking, jogging, or squatting. Increased stress or angles of the knee cause stress, inflammation, and pain (McClure, et. al, 2005). Women that participated in athletics in their high school years are also more likely to develop musculoskeletal disorders as they age. Stress put on the body from sports never recovers completely when stress from the working environment is added (McClure, et. al, 2005). Women have shoulder injuries that affect how the shoulder and arm works. Issues with the rotator cuff, biceps, and instability of the shoulder joint occur when the arms have been kept over the head working or working with increasing weight loads.

Foot disorders are also common in working women, as women's feet are narrower than men's and they often wear shoes that are not supportive or comfortable (McClure, et. al, 2005). Stress fractures as related to the listed issues occur more in women, but it is unknown if due to bone density or hormones (McClure, et. al, 2005). Over three-quarters of injuries that occur during work are in the lower parts of the body, with back pain being the most common (Borman, 2011). Women may be able to reduce these instances by changing their physical activity level outside of work.

Working, as well as social activities and social behaviors can contribute to the higher risk of musculoskeletal disorders in women. Women also have higher muscle fiber proportions than men, making women have higher endurance but work longer and cause more damage (Institute for Work and Health, 2016). Women and men move, react to pain, act in response to fatigue and stress differently; they also have different duties outside of work that also contribute to overusing the body in ways that cause harm to itself. These factors may explain the circumstances women are under when suffering from musculoskeletal disorders (Institute for Work and Health, 2016).

2.2 Typical Fields Where Women are Employed

The top three fields for women to be employed in are healthcare (registered nurses, psychiatric, home health aides), secretaries and administrative assistants, and teachers; the bottom three fields for women to be employed in are cooks, social workers, and waitresses (Department of Labor, 2015). Of these jobs listed, healthcare is one of the main focuses where exoskeleton use could be helpful. Women make up around 95% of the healthcare field, and they often suffer from more

musculoskeletal disorders than their male counterparts, who only make up 10% of the healthcare field (Department of Labor, 2015).

However, women are employed in more than just the healthcare field. Women made up 46.9% laborers last year, broken down into various industries (Bureau of Labor Statistics, 2018). Women make up 29.2% of the manufacturing industry, 9.9% of the construction industry, and 41.5% of professional and business services (Bureau of Labor Statistics, 2018). Healthcare and education have been the highest industries for women employment for quite a while and seems that it will stay that way in the future (Bureau of Labor Statistics, 2009). Women make up roughly 40% of jobs where nearly three quarters of those workforces are mainly women (DeWolf, 2017). Women in the labor force has been steadily increasing, almost doubling in 70 years (DeWolf, 2017). Although women are still underrepresented in many STEM (science, technology, engineering, and math) fields, they are increasing in other fields like business and managerial positions; the unemployment rate is also down almost half in less than ten years (DeWolf, 2017).

When broken down by numbers, women make up one in four employees in "men's jobs": 1.3% women to 11.1% men in the construction industry, 6.6% women to 14.4% men in any manufacturing related industry, and 3.0% women to 7.8% men in the transportation and communications industries respectively (Status of Women Data, 2019). Many women branch out into these fields, but not enough to make a large difference in the workforce. These statistics can also differ by state; for example, the state of Ohio gets a C- grade and ranks number 33 in the states on the list of employment in each state (Status of Women Data, 2019). The wage gap may have to do with women's lack of interest in more physically demanding jobs, even though more women have bachelor's degrees before men; over half of women would earn more if paid the same as their counterparts that work the same shift and have the same level of education (Burke, 2017).

Women veterans also make up a percentage of the workforce (Department of Labor, 2014). These individuals made up 12.8% of the workforce in 2013, which was also the highest of any women veterans in the workforce from both Gulf War eras (Department of Labor, 2014). Women veterans work primarily in private sector jobs at 66.9%, but also work in the following industries: the federal government at 13.7% employment, local government at 8.2% employment, state government at 6.8% employment, and self-employment at 3.9% employment (Department of Labor, 2014).

Mothers are also taken into consideration in the workforce. Because of financial issues or simply a want, many mothers work outside the home. Mother with children under the age of 18 made up 69.9% of the labor force in 2013, with all mothers making up a total of 57.2% of the labor force that year (Department of Labor, 2013). Within all women, there was a 10.9% increase between 1975 and 2013 (Department of Labor, 2013). The greatest number of mothers that participate in the workforce have children between ages six and seventeen at 74.7%, and the least number of mothers have children under the age of one at 57.3% (Department of Labor, 2013).

In the healthcare field, women make up the majority of employees. Women were 98% of dental hygienists in 2011, with a projected growth of 38% within the next ten years and were 91% of registered nurses in the same year, with the projected growth of 26% within the next ten years (Department of Labor, 2012). Health care and social assistance are projected to be the two fastest growing career fields, and even more so for women; 44% of new jobs will be in these fields in the next ten years (Department of Labor, 2012). Registered nurses will grow by almost 800 thousand in the next ten years, possibly resulting in more injuries (Department of Labor, 2012).

2.3 Occupational Skeletons Overview

Because of physical work demands, many employers may want to switch to semi-automated or fully automated work environments to streamline their systems. However, it may be difficult or cost prohibitive to do that and companies are considering exoskeletons as a way to reduce the risk of musculoskeletal injury. Passive exoskeletons for occupational purposes can be categorized as providing shoulder, back, leg, tool, or seating support. One example of an industry that might consider using exoskeletons is the material handling industry, or the material handling area in a plant of any kind (DeLooze, et al., 2015). A material handling facility might benefit from a passive exoskeleton, which keeps posture more consistent and uses stored energies to help employees accomplish tasks (DeLooze, et al., 2015). Passive exoskeletons have been found to be helpful in cases of lifting and bending, and fatigue levels are not as high as working without a suit (DeLooze, et al., 2015).

A large focus of future exoskeleton technology is how to decrease the possibility of musculoskeletal disorders affecting workers (Burris, 2018). The workforce could be expanded because older people and people of lesser physical strength would be able to work in the same position (Burris, 2018). While suits can be bulky and large, a look into the future predicts that they should become more compact and weigh less as designs progress (Burris, 2018).

Because of the variability and differences of tasks that exoskeletons may encounter, it is important that multiple types of exoskeletons that are used for the same purpose be tried before settling on one type for everyone—what works for one employee may not work for another. Often in laboratory studies, multiple types of exoskeletons will be experimented with to see which achieves the best results (Picchiotti, et al., 2019). Passive exoskeletons are more widely used in industry, based on their availability, price, and ease of use (Picchiotti, et al., 2019). Knee injuries, lumbar spine loading, and lower

back injuries are some concerns that should be addressed when fitting exoskeletons; suits should be chosen with these issues in mind (Picchiotti, et al., 2019). Activities like lifting (squat versus straight formation), twisting, lifting tools above the head are all candidates for exoskeleton wear.

A common issue that arises with back exoskeletons includes putting pressure on different parts of the body that wouldn't have been affected otherwise (Baltrusch, et al., 2018). Another issue with current exoskeletons is that they are most often created to assist the wear with only one task, while employees are required to perform more than one task in their job (Baltrusch, et al., 2018). Many of the tasks that must be taken into consideration when designing an exoskeleton include lifting, carrying, holding tools or equipment over the head, walking, trunk rotation, and stair climbing (Baltrusch, et al., 2018). Because of the design of current exoskeletons, they decrease the performance of tasks and increase the difficulty of the jobs being done (Baltrusch, et al., 2018).

One option that has been explored and may be extended in the future is combining programming with exoskeletons to create a suit that is programmable for different tasks, as well as controlling degrees of freedom to keep motions of joints more human-like (Souza, et al., 2016). Many instances when researching or discussing exoskeletons, it seems that requirements are often overlooked in the design process. Although modeling is important to understand how a suit will work, designing a suit with the job requirements in mind is a step that is frequently dismissed (Souza, et al., 2016).

While passive exoskeletons are the most common used in industry, electric powered suits are an option that is being explored that may be helpful in the future (Zoss and Kazerooni, 2006). This kind of technology could be something that turned itself on and off, depending on the task being performed or the weight that is being handled (Zoss and Kazerooni, 2006). Most of these exoskeletons would be powered with pneumatic parts, making for portable power supply that is influenced by the force a human is exerting (Zoss and Kazerooni, 2006). Another technological development would be the use of electric motors powered by electromyography sensor on the body of the suit (Zoss and Kazerooni, 2006).

At the end of the day, safety should be one of the main concepts taken to mind when designing an exoskeleton. If an exoskeleton is not safe, then it should not be produced and released for use. Safety in exoskeletons consists of many elements, including where weight from the suit will be applied, skin irritation on the wearer from the suit, or strain on the wearer's body at any point while wearing the suit (Bostelman and Hong, n.d.). There are many performance indicators that should be tested including how a suit navigates, the perception a suit has with its wearer, how the suit manages tasks, and how the suit is manipulated by the wearer (Bostelman and Hong, n.d.). These indicators may be biased by outside influences like duration of task, speed used during task, acceleration or deceleration the exoskeleton reaches during a task, uncertainty in posing of the suit, control force being used when moving parts of the suit, vertical or horizontal navigation of the exoskeleton versus other factors, ease of use of the suit, the ergonomic aspects of the suit, and the difficulty of putting the suit on or taking it off (Bostelman and Hong, n.d.).

For all their advantages, exoskeletons also have some disadvantages. Exoskeletons are costly, bulky, ill-fitting, and take time to produce (New York University, 2015). Exoskeletons can be uncomfortable, bulky, limit movement and come with a negative connotation when worn (DeLooze, et al., 2015). If discomfort levels and weight could be decreased in the design, people might be more willing to wear one in the workplace. With specific regard to women, some of the designs place pressure on the chest area, which may be very uncomfortable.

Anthropometry is becoming one aspect that is pushing to the forefront of exoskeleton design (Pu, et al., 2016). Taking measurements of each body part that has a corresponding exoskeleton part could ensure that the suit part matches with the dimensions of the wearer (Pu, et al., 2016). If large anthropometric areas are measured, for example the top 95 percentile of men and top 95 percentile of women, then there are more available data points to pull from when design certain limbs on an exoskeleton (Pu, et al., 2016). Simulation should also be considered when designing with anthropometric measurements; using a simulated event could determine whether the percentiles are large enough to pull the necessary data points from (Pu, et al., 2016).

3. Opportunities for Research

Although much research has been started on passive exoskeletons for work, much more work needs to be done to ensure that they are designed for the female workforce. This includes measuring female workers, finding the correct exoskeleton for the job, and observing opinions related to exoskeletons. Measuring the anthropometry of female workers will help determine if exoskeletons are fitting these employees. Ensuring the correct exoskeleton is being used for the job ensures that the exoskeleton is being helpful instead of harmful. Opinions on exoskeletons can be a determinant if exoskeletons are being used on the job based on the connotation associated with it.

New design elements could include adjustable hip joints, longer straps across the chest, wider variety of anthropometry used, an adjustable spine meant for different torso lengths, and better padding in certain areas to improve comfort. When adding these features to current designs, those suits could serve a larger customer base. Adjustable hip joints

allow consumers with wider hips to wear the suit comfortably, while still performing duties as usual. Longer straps across the chest ensure that people with wider chests are still protected but are not squeezed into a standard width. Using a wider variety of anthropometric measurement ensures that not only can the top 95 percentile of men can fit into an exoskeleton, but the bottom 95 percentile of women can wear the same exoskeleton.

Exoskeletons need to be able to be used for occupations that are common for female employees including healthcare, manufacturing, and retail. In addition to the sizing and design of exoskeletons, challenges may exist related to the perception of the use of exoskeletons and aesthetics. Designers should consider the psychological factors related to both wearing an exoskeleton and the perception by others. Jobs that require heavy lifting, twisting, overhead work, or limbs in constant positions for periods of time would benefit from having an exoskeleton introduced to the work being performed.

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