



A Literature Review of Trends in Personal Protective Equipment

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Abstract. Personal Protective Equipment (PPE) is used in varying degrees across any industry where the work poses a threat to human safety. It ranges from protective glasses worn by a machinist to full-on hazmat suits used to work in areas with high radiation and everywhere in between. The impact of PPE is undeniable as it allows industrial entities to protect their workers from serious harm as well as shielding them from liability. By adequately using the appropriate and properly fitted PPE for any given task the risk of injury can be drastically reduced. This can clearly be illustrated by the U.S. Bureau of Labor Statistics which found that the rate of non-fatal workplace injuries or illness decreased by 70% from 1972 to 2018 [1]. The increased attention to PPE has paid dividends in worker safety since its popularization in the 1970s, and even today industry leaders in professional safety groups are hard at work to develop PPE that is safer and more accessible than ever before.

Keywords: Personal Protective Equipment (PPE) · Industry Safety · Workplace Accident · Safety Ergonomics · Anthropometry

1 Introduction and Background

The topic of personal protection equipment (PPE) is vital to many industries for the basic protection of their workers. From the U.S. Department of Labor-Occupational Safety and Health Association (OSHA) PPE is equipment worn to minimize exposure to hazards that cause serious workplace injuries and illness. For companies to maintain their workforce, they must protect their employees by following industry standards for basic safety protocols [2]. PPE can range from eye and ear protection to gowns and full suits depending on the hazards the job may present.

The focus of PPE first showed importance in the 1920s, then became a serious topic of interest in the 1970s. There have always been hazardous jobs in the workforce, but engineers have access to more capabilities than ever to create the best gear and equipment for workplace environment safety.

Furthermore, Personal Protective Equipment is a crucial part of industrial engineering because it allows human workers to safely work in industrial settings without significant risk of injury. Proper PPE improves efficiency, keeps workers safe, limits

company liability, and allows workers to use industrial machinery they wouldn't be able to otherwise.

Beyond industrial engineering, a focus on PPE is valuable in any setting where human injury is at risk. This includes factory workers, inspectors, medical professionals, and much more. A recent example is the focus placed on PPE to combat Covid-19. National broadcasts went out throughout 2020 to educate the population on the proper use of PPE to protect themselves, and the Human Factors and Ergonomics Society even had a hand in developing safe practices for the use and reuse of COVID-19 PPE. Industries everywhere are working to optimize their use of PPE to mitigate human liability.

Although we have made great strides in worker safety and PPE over the past 50 years, we still have a long way to go on making PPE accessible and tailored to an increasingly diverse workforce. For example, women are far more likely to be put at risk than their male counterparts due to ill-fitting safety gear. A survey conducted by the Center for Construction Research and Training asked 174 female workers about their experience with PPE, and found that 77% of them had been put at risk due to ill-fitting safety gear. This goes to show that a traditionally male-dominated trade, like construction, is not adapting fast enough to a changing workforce to adequately protect employees.

Finally, human factors and ergonomics are closely tied to personal protective equipment since PPE directly interfaces with human workers. As such it is imperative that designers of PPE have a good understanding of human factors and anthropometry. The Human Factors and Ergonomics Society works to develop anthropometric standards that are used to evaluate the fit of industry protective equipment, per "ISO 15537:2004 Principles for selecting and using test persons for testing anthropometric aspects of industrial products and designs." [5]. This helps ensure that a wide variety of people with different body types can effectively and safely use well-fitted PPE.

This systematic literature review aims to explore the history and applications of PPE, from the past to future developments [26, 27]. PPE is a generalized term that is used across multiple industries, ranging from automotive, medical, aviation, and civil engineering work. PPE is a vital piece of equipment for the safety of persons in various environments. Historically it ranges from basic protection gear such as ear muffs or safety eyeglasses to guards on automated arms on assembly lines. The construction of these materials is not quite as simple. Safety testing is conducted for any piece of equipment or clothing considered PPE to ensure it holds up to its standards, which are set by material properties and also by OSHA. Thanks to rapidly developing technologies across a myriad of industries, PPE has become more important than ever and will need to remain an evolving field of study and relevance.

1.1 Definitions

Personal Protective Equipment: Personal protective equipment, commonly referred to as "PPE", is equipment worn to minimize exposure to hazards that cause serious workplace injuries and illnesses. These injuries and illnesses may result from contact with chemical, radiological, physical, electrical, mechanical, or other workplace hazards. Personal protective equipment may include items such as gloves, safety glasses and shoes, earplugs or muffs, hard hats, respirators, coveralls, vests, and full-body suits.

Workplace Accident: According to OSHA a workplace accident is an unplanned event that results in personal injury or property damage during or arising out of work performed in the course and the scope of employment [3].

Anthropometry: Anthropometry is the science that defines physical measures of a person's size, form, and functional capacities. Applied to occupational injury prevention, anthropometric measurements are used to study the interaction of workers with tasks, tools, machines, vehicles, and personal protective equipment—especially to determine the degree of protection against dangerous exposures, whether chronic or acute [4].

2 Purpose of Study

While research into PPE was first popularized in the early 1970s with the founding of OSHA and the rise of labor and workplace safety regulations, the last five years have seen a surge in research spearheaded by the response to COVID-19, but still readily apparent in other industries. This study will seek to understand what is driving PPE as an emerging topic as well as a mainstay of scientific research. Bibliometric analysis will allow us to understand what topics of PPE are driving most modern research as well as where that research is taking place. Data was collected using a wide variety of databases including Scopus and Google Scholar, and then visualized using metadata tools like Citespace, Scopus, google Ngram, and Nvivo.

3 Procedure

To analyze relevant findings related to PPE along with its use within multiple industries and future work for innovation, a bibliometric analysis was conducted along with data searching tools. This analysis measures the engagement of researchers and the relevance of PPE related to ergonomics in society. A trend analysis, keyword search analysis, identification of emergence, and general data collection will be discussed all concerning PPE.

The sources referenced in this literature review are intended to assist in the bibliometric analysis of the topic of PPE in ergonomics and to relate current and previous research conducted to the relevance of the topic of PPE in society. Scopus, CiteSpace, Google nGram, and VOSviewer are examples of analysis tools that aid in understanding the prevalence of PPE. Research articles from various sites such as Scopus, Google Scholar, and PubMed are referenced to expand on the importance of PPE and how it is currently and previously understood, researched, and applied in various applications and work settings.

3.1 Identifying Driving Factors of PPE Research

See Table 1.

Table 1. A tabulation of the documents found using Scopus to search for PPE and Workplace Accidents using various filters.

Search Terms	Database	Search Parameters	Number of Articles
Personal Protective Equipment	Scopus	No Restrictions	17,776
	Scopus	1972–2023	17,749
	Scopus	Engineering Documents	2,577
Workplace Accident	Scopus	No Restrictions	9,472
	Scopus	1972–2023	9,469
	Scopus	Engineering Documents	2,915
Anthropometry	Scopus	No Restrictions	94,932
	Scopus	1972–2023	92,424
	Scopus	Engineering Documents	5,547

3.2 Data Visualization Methods

The citation methods used for this systematic literature review were inspired by: “Methodology for Systematic Literature Review Applied to... - IEEE Xplore.” IEEE Conference Publication. Accessed November 27, 2023. <https://ieeexplore.ieee.org/abstract/document/8363388>.

The following methods were used to find trends, relationships, and current research being conducted for PPE in multiple applications (medical, industrial, automotive, etc.)

1. CiteSpace analysis research articles for trends in the representation of a topic and linkages between authors.
2. VOSViewer is used to construct a bibliometric network of relations between authors and publications.
3. Google nGram displays a string of frequencies of searched topics compared to their relevance factor in time.

4 Results and Discussion

4.1 Trends in PPE Research

The focus of PPE first showed importance in the 1920s, then became a serious topic of interest in the 1970s. There have always been hazardous jobs in the workforce, but engineers have access to more capabilities than ever to create the best gear and equipment for workplace environment safety [5].

The key search terms used were “personal protection equipment”. It can be inferred from the data displayed in Fig. 1 that the COVID-19 pandemic was a large cause of the spike seen in 2020 for articles published related to personal protection equipment (Fig. 2).

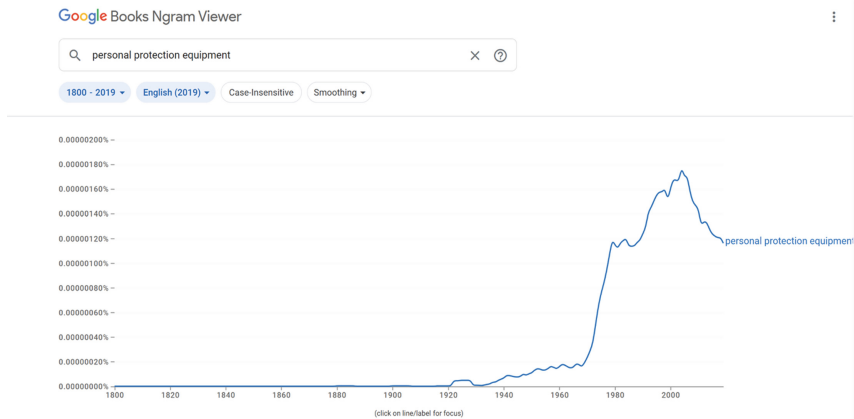


Fig. 1. Google nGram comparison of a keyword search of “personal protection equipment” and displaying its relevance between the years of 1800 to 2019.

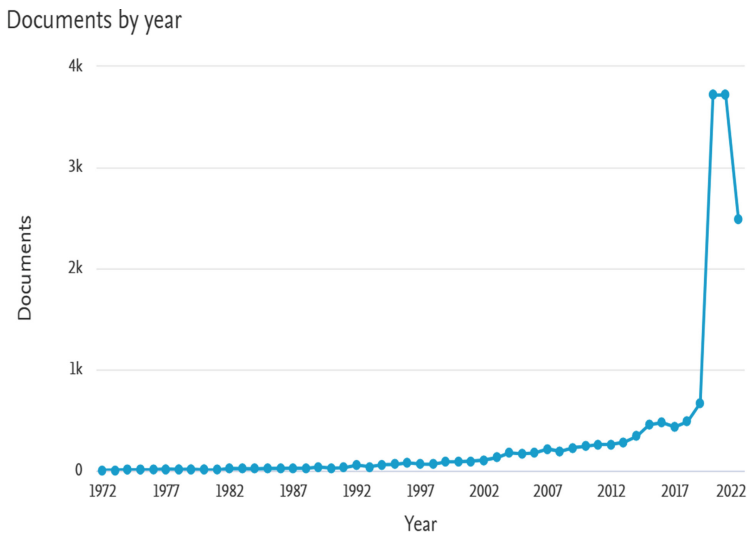


Fig. 2. Number of documents about personal protective equipment published in Scopus from 1972 to 2022.

According to Scopus, in 2017 432 documents related to PPE were released compared to 3,718 documents released in 2021. I would attribute this to the global focus on PPE regarding coronavirus that has been ongoing since 2020. This accounts for the surge in over 8 times as many documents released compared to just 4 years prior. An astonishing 43.4% of Scopus PPE documents are related to the medical field, while the next largest field was engineering with only 9.3%. This of course begs the question of does this trend extends to other industries across this same five-year period, or is it isolated to medical PPE?

When examining solely engineering-related documents we found that 98 PPE documents were released in Scopus in 2017, and 314 were released in 2021, which is over 3 times as many. This means that although the trend did not exist to the same extent it did in the medical field, the global focus on PPE in recent years is not solely based on COVID-19, which solidifies PPE as both a staple of ergonomics and an emerging technology.

It is difficult to tell in the figure above but Scopus articles first started being submitted around 1972 and saw a steady increase until 2020 when a massive influx of submissions coincided with the beginning of the Covid-19 pandemic. In 2022 this number started to decline as the Covid was better understood and less widespread.

4.2 Leading Sources of PPE Research

Through our research, we have identified several leading articles related to PPE and ergonomics summarized in Table 2 below. Of the five top articles four of them are about medical PPE, one of which is specifically about Covid-19, and the fifth is about PPE for construction workers. This reflects the recent national focus on medical PPE to combat a global pandemic. Specifically, the leading PPE article discusses how medical PPE, which is often cumbersome, impacts the ability of medical professionals to do their jobs. Reduced visibility, reduced dexterity, and overheating are just some of the factors that could result in mistakes being made [23]. This is particularly interesting because the most cited article has nothing to do with improving the effectiveness of PPE, but rather to prevent it from getting in the way.

The second leading article surveyed construction workers to identify the physical pain they experience during their jobs. This data will be used to develop new PPE specifically targeted to reduce these aches and pains [24]. Finally, the third leading article is about minimizing the risk of contagion during an endoscopic procedure. The article also discusses the importance of considering additional factors when selecting PPE, such as patient allergies to some synthetic materials and the ability of surgeons to do their job despite PPE being in the way [25]. These articles give us a better idea of not only what the leading topics in today's research are, but ideas as to where they will go in the future.

The main topic of PPE demonstrated in many of these articles that related to COVID-19 was equipment that can be made to fit-for-all or fit for a general population was highlighted throughout many articles. The benefit of a universal fit is fast production times, simple manufacturing equipment (non-variable), and overall low cost to produce, which then means the product can be more affordable to purchase. The other caveat to COVID-19 was the governmental requirements for certain PPE and disinfecting procedures in public spaces. This nuance caused a massive bottleneck in the manufacturing industry by a large request for production of the PPE, shortage of materials, low staffing, and high demand.

These research articles referenced in this systematic review have been identified as overlapping [6, 15], as they are both about personal protection equipment during the COVID-19 pandemic. These articles were cross-checked by comparing the Scopus information about the index keyword used.

Table 2. Identified 5 top leading articles about PPE and ergonomics were cited the most, using Scopus as an identification source. 85 articles were identified as related to PPE in ergonomics using the general keyword search tool in Scopus from 2010 to 2022.

Author	Article Title	Leading Keywords	# of Citations
Martina Loibner	<u>Scopus - Document details - Limiting factors for wearing personal protective equipment (PPE) in a health care environment evaluated in a randomised study</u>	Adult; Body Temperature; Ergonomics	93
S. Eaves	<u>Scopus - Document details - Building healthy construction workers: Their views on health, wellbeing and better workplace design</u>	Ageing; Construction ergonomics; Health and wellbeing; Participatory ergonomics	91
Marcos C. Pedrosa	<u>Scopus - Document details - Minimizing occupational hazards in endoscopy: Personal protective equipment, radiation safety, and ergonomics</u>	clinical study; data base; ergonomics	76
Massimiliano Sorbello	<u>Scopus - Document details - Aerosol boxes and barrier enclosures for airway management in COVID-19 patients: a scoping review and narrative synthesis</u>	aerosol box; aerosol-generating procedures; COVID-19; droplets; intubation box; tracheal intubation	75
Lorna K.P. Suen	<u>Scopus - Document details - Self-contamination during doffing of personal protective equipment by healthcare workers to prevent Ebola transmission</u>	Adult; Aerosols; Environmental Exposure; Female	75

Additionally, we have identified the top 5 research institutions for PPE development which are summarized in Table 3 below. Unsurprisingly they are all either medical research institutions or larger research institutions that have a strong presence in the medical field. What is more surprising is just how much more research was conducted at the top institution, The National University of Singapore. The National University

of Singapore has nearly twice as many research documents as the next four highest institutions combined.

This is likely partially because the University of Singapore is being evaluated as a single entity whereas other institutions like Harvard Medical School have its research counted separately from the main Harvard University’s total. Regardless, this doesn’t adequately explain this discrepancy. Therefore, we are forced to conclude that medical PPE and likely other forms of PPE are prioritized highly at the National University of Singapore, as that priority is reflected in the sheer volume of their research.

Table 3. The Top 5 leading institutions in the research of personal protection equipment from topic search in Scopus. Researchers were identified by referencing the key search words “Ergonomics” and “PPE”. The results were then filtered by the highest number of citations with the keywords used to search. This data is based on results matching documents since 2019.

Institution	Country	# of Documents
National University of Singapore	Singapore	1984
University Hospital Bern,	Switzerland	316
Medizinische Universität Graz	Austria	308
Università degli Studi di Firenze,	Italy	202
Harvard Medical School,	United States	197

An additional analysis was conducted using VOSViewer and CiteSpace for a co-author analysis that represents relations in the field of ergonomics, specifically related to personal protection equipment, and can be seen in Figs. 3 and 4 below. The VOSViewer analysis displays an intricate web of relations between authors in Fig. 3. In Fig. 4, it can be inferred that many articles are cross-referenced by each other, which is represented by the smaller clusters encircled by a larger cluster.

4.3 PPE in Various Industrial Applications

Given the dominance of the medical field in PPE research and the enormous spike in research published at the start of the Covid-19 pandemic, we thought it would be more diverse and interesting to examine keywords used only in engineering articles about PPE as shown in the word cloud above. In this word cloud, we see the biggest words are personal, protective, equipment, safety, arc, and flash, The first four words are fairly self-explanatory, but arc and flash show that a significant amount of research is focusing on PPE to protect workers from electrical arcing and bright flashes that could damage retinas.

If we look around these core words (see Fig. 5) we can see keywords that give us clues about what types of PPE is being discussed most and what sorts of hazards they are intended to guard against. For example, clothing is a large word, which would lead us to believe that there is a large focus on PPE clothing rather than accessories like glasses or a harness. Potential risk words include fire, electrical, and pesticide which show there is a wide variety of dangers PPE needs to guard against.

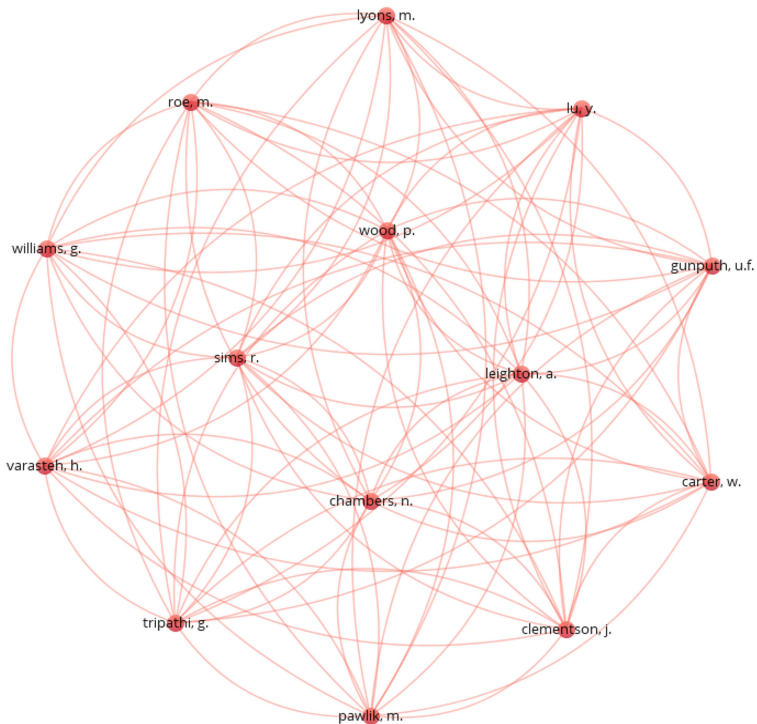


Fig. 3. Analysis conducted in VOSviewer. This co-analysis of author relations represents the authors and their relations to others in the field of ergonomics. The authors referenced in this article [5] are all co-authors from a research study of one-size-fits face shields for users during the 2020 COVID-19 pandemic to decrease the variability and cost, but allow face shields to be most accessible to users.

Personal Protective Equipment is a crucial part of industrial engineering because it allows human workers to safely work in industrial settings without significant risk of injury. Proper PPE improves efficiency, keeps workers safe, limits company liability, and allows workers to use industrial machinery they wouldn't be able to otherwise.

While PPE is an integral part of industrial engineering it also exists in any setting where human injury is at risk. This includes factory workers, inspectors, medical professionals, and much more. A recent example is the focus placed on PPE to combat Covid-19. National broadcasts went out throughout 2020 to educate the population on the proper use of PPE to protect themselves, and the Human Factors and Ergonomics Society even had a hand in developing safe practices for the use and reuse of COVID-19 PPE [20]. Industries everywhere are working to optimize their use of PPE to mitigate human liability (Fig. 6).

We were surprised to see arc and flash and some of the biggest keywords in our word cloud generated by nVivo, which prompted us to search through Scopus to see how many articles were published relating to arc personal protective equipment. In total there are 214 articles, whose distribution can be seen in the figure above. It looks like



Fig. 4. Analysis conducted in CiteSpace. This co-citation analysis pairs articles that have been cited together within multiple other articles. Ninety-one (91) records were discovered in Web of Science based on the key search terms “ergonomics” and “PPE”. These 91 articles were then analyzed by citation occurrence. It should be noted that there were no citation bursts discovered within these 91 reference articles.

PPE to protect people from electrical arcs was not researched thoroughly until 1996 and became more popular around 2004. This is interesting because electrical arcing has been a danger to people since the widespread implementation of electrical power, and arc welding was developed as far back as the late 19th century. There was likely some technological innovation that increased the rate of human exposure to electrical arcs around 2004, which contributed to further research into arc PPE.

4.4 Relevance to Human Factors and Ergonomics

Trends in PPE are related to several chapters in the 5th edition of the Handbook of Human Factors and Ergonomics, but two of them are of particular interest. First, the entire 25th chapter titled Use of Personal Protective Equipment is highly relevant to our literature review of trends in PPE as it details the applications for several PPE devices including respirators, helmets, and much more. Section 2 of Chapter 25, Selection of Respiratory Protective Devices for Different Types of Workplaces [17], starting on page 669 is especially relevant for recent research in PPE as it has been focused on developing better masks to guard against viral infection. The chapter is largely about the use of industrial respirators that filter out gasses and particles either through the use of a filter



Fig. 5. Word cloud generated by nVivo using keywords from engineering documents about PPE on Scopus.

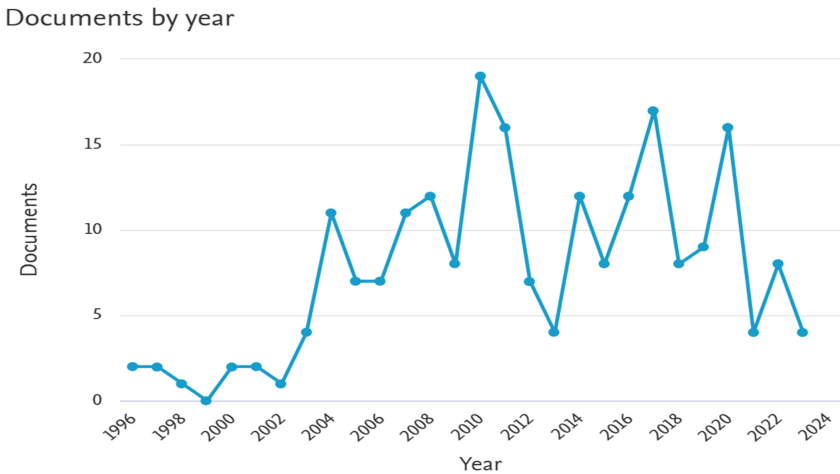


Fig. 6. The number of documents about arc personal protective equipment published in Scopus from 1996 to 2023.

or an external oxygen tank. These devices may not be directly related to the medical-grade masks discussed in the future work section, but the principles of selecting the proper breathing device for a given situation can still be applied.

The second related chapter is Chapter 11: 3D Anthropometry and its Applications in Product Design [18]. As discussed earlier, since PPE is equipment that is worn by and interfaces directly with humans it is important that PPE can fit different body types.

Anthropometry can be used to simulate human proportions and aid in the rapid design and prototyping of PPE. Section 5 of this chapter titled, Application in Product Design, discusses how this data can be used to aid design processes for both static and dynamic applications, which PPE is often subject to both. Their discussion of adapting to different body dimensions and height and weight percentiles is also particularly relevant.

PPE challenges are also relevant to our work in vehicle interiors that was performed in RAMSIS for Lab 2. In that lab, students were asked to position cockpit controls in such a manner that they were comfortable for pilots ranging from a 5th percentile female to a 95th percentile male representing a wide range of body types and pilot sizes. These same lessons can be applied to the development of PPE. Protective gear is only effective if it adequately fits the wearer. If it is too loose or too tight, not only will it distract workers from their jobs, but could cause them to take it off while performing dangerous work if it is too uncomfortable. Finally, PPE is directly related to multiple chapters we discussed in the 5th edition Handbook of Human Factors and Ergonomics, as discussed in the preceding paragraphs.

5 Conclusions and Future Work

5.1 Importance of PPE Research

PPE research is often limited in scope to a particular industry. After all, there are significant differences in the PPE needs among different industries. Medical professionals don't need the same protective gear factory workers do and vice versa. This literature review seeks to better understand commonalities and differences in the challenges faced by different industries in developing and employing PPE. For example, protective eyewear sizes do not vary that much between individuals with different body types in the same way more full-body gear would. Therefore, protective eyewear companies don't need to worry as much about developing different products that fit various sizes of workers.

PPE developers also need to be aware of more recent changes to their customer demographics. Certain fields like construction have been male-dominated for decades and are now seeing more and more women step into those roles. Women need different-sized hard hats and safety vests, but these aren't particularly difficult engineering problems to solve. PPE companies can easily resize existing products to fit the new workforce, but the greater issue is in the distribution and implementation of appropriately sized PPE and the impact that has on construction companies. Some companies could be reluctant to purchase new safety equipment for women, which could lead to either women wearing poorly fitted men's safety equipment or the company refusing to hire women at all.

There were various articles found that pertained to the development and future of PPE, especially after the events of the COVID-19 pandemic. Table 4 outlines the articles that were identified for future work on an analysis for PPE. These articles will be used to expand on the impact PPE had during the pandemic and the outcomes of further improvements for PPE during critical times.

5.2 Societal Influences

Society needs to put a greater emphasis on making PPE accessible and tailored to an increasingly diverse workforce. For example, women are far more likely to be put at

Table 4. A brief list of key articles, found from a co-citation analysis will be used for a more depth of analysis regarding the topic of PPE. This analysis will aid in the understanding of the new methodology that is being used to ensure the safety and protection of persons.

Article Title	Citation	Intentions for Review
Human factors issues of working in personal protective equipment during the COVID-19 pandemic [7]	Hignett, S., Welsh, R., Banerjee, J Human factors issues of working in personal protective equipment during the COVID-19 pandemic (2021) <i>Anaesthesia</i> , 76 (1), pp. 134–135 http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1365-2044 doi: https://doi.org/10.1111/anae.15198	This article will aid as a general overview of PPE concerns due to the COVID-19 pandemic
Headaches due to external compression [8]	Krymchantowski, A.V Headaches due to external compression (2010) <i>Current Pain and Headache Reports</i> , 14 (4), pp. 321–324. Cited 52 times doi: https://doi.org/10.1007/s11916-010-0122-x	Face masks and shields were common PPE tools that were required in many working settings during the COVID-19 pandemic. This article will aid in understanding the effects face masks had and the ergonomic impact it had on a person's head
Unmasking the myths surrounding use of barrier face coverings during the COVID-19 pandemic [9]	Liew, C.H., Flaherty, G.T Unmasking the myths surrounding use of barrier face coverings during the COVID-19 pandemic (2020) <i>Int. J. Travel Med. Global Health</i> , 8 (4), pp. 134–136	This article will serve as an opposing view to the use of face masks and other PPE during the pandemic
The Supply of Personal Protective Equipment (PPE) during the COVID-19 Pandemic. [10]	Davies, G (2020) The Supply of Personal Protective Equipment (PPE) during the COVID-19 Pandemic D.o.H.a.S. Care National Audit Office: https://www.nao.org.uk/wp-content/uploads/2020/11/The-supply-of-personal-protective-equipment-PPE-during-the-COVID-19-pandemic.pdf	This research will explore the limitations of PPE
Facial anthropometric differences among gender, ethnicity, and age groups [11]	Zhuang, Z., Landsittel, D., Benson, S., Roberge, R., Shaffer, R Facial anthropometric differences among gender, ethnicity, and age groups (2010) <i>Annals of Occupational Hygiene</i> , 54 (4), pp. 391–402 doi: https://doi.org/10.1093/annhyg/meq007	This research supports the use of face masks by gaining insights to the design of facemasks by understanding the anthropometrics for general populations

(continued)

Table 4. (continued)

Article Title	Citation	Intentions for Review
Comfort evaluation of hearing protection [12]	Hsu, Y.-L., Huang, C.-C., Yo, C.-Y., Chen, C.-J., Lien, C.-M Comfort evaluation of hearing protection (2004) <i>International Journal of Industrial Ergonomics</i> , 33 (6), pp. 543–551 www.elsevier.com/locate/ergon doi: https://doi.org/10.1016/j.ergon.2004.01.001	This analysis will support the use of ear protection and how to make it more ergonomically comfortable for the user
Hearing protectors: Noise attenuation and comfort [13]	Gerges, S.N.Y Hearing protectors: Noise attenuation and comfort (2010) 39th International Congress on Noise Control Engineering 2010, INTER-NOISE 2010, 1, pp. 34–52 ISBN: 978-161782396-1	Along with anthropometric research, this article will give perspective to another type of personal protective equipment for the ears
Factors contributing to discomfort or dissatisfaction as a result of wearing personal protective equipment. [14]	Akbar-Khanzadeh, F Factors contributing to discomfort or dissatisfaction as a result of wearing personal protective equipment (1998) <i>Journal of human ergology</i> , 27 (1–2), pp. 70–75	Research conducted will analyze PPE as a general topic and dissatisfaction by the users

risk than their male counterparts due to ill-fitting safety gear. A survey conducted by the Center for Construction Research and Training asked 174 female workers about their experience with PPE, and found that 77% of them had been put at risk due to ill-fitting safety gear [14]. This goes to show that a traditionally male-dominated trade, like construction, is not adapting fast enough to a changing workforce to adequately protect employees.

Human factors and ergonomics are closely tied to personal protective equipment since PPE directly interfaces with human workers. As such it is imperative that designers of PPE have a good understanding of human factors and anthropometry. The Human Factors and Ergonomics Society works to develop anthropometric standards that are used to evaluate the fit of industry protective equipment, per “ISO 15537:2004 Principles for selecting and using test persons for testing anthropometric aspects of industrial products and designs.” [20]. This helps ensure that a wide variety of people with different body types can effectively and safely use well-fitted PPE.

One of the listed ten ways to analyze new and existing research is to carefully consider your background information. This helps to interpret trends that we are seeing in the metadata we have gathered. For example, our research shows that there was a sharp increase in PPE-related research documents in 1972 and again in 2020. To

understand these trends, we need to remember the major events of those eras that would have a profound influence on the development and research of PPE. For example, the coronavirus pandemic began in 2020 which sparked national debate on effective PPE measures. Naturally, this led to a large increase in PPE documents submitted to scientific databases.

In 1971, the Occupational Health and Safety Administration or (OSHA) was founded which sought to standardize workplace safety practices across the nation. OSHA's influence mandated programs like inspections, mandatory workplace accident reporting, and a plethora of other safety improvements that extend to PPE [21]. By examining metadata trends, we don't currently understand it is best to dig into the historical context and background information available to get a better understanding of the full picture. After all, metadata can tell us what kinds of trends occurred in a topic, but not why they occurred, which is why background information creates new ways to gain insight into the metadata,

5.3 Covid-19 PPE

In our literature review of PPE the most popular field was the medical field and the most popular sub-topic was Covid-19-related PPE. Of those articles, a consistent focus was on developing products that can adapt to and fit a diverse population. The benefits of developing a one-size-fits-all product include cheaper manufacturing costs, easier distribution, and in turn a more affordable product for the general public. There are certainly cases when a more tailored approach is required for individuals like health care workers with high rates of exposure, but for the general public, the benefits of a one-size-fits-all approach far outweigh the negatives.

Other articles discussed how government and company policies on PPE and disinfecting created a significant manufacturing challenge for the industry. People were required to wear masks and gloves and disinfect surfaces which created a massive demand for these sanitation and PPE products that the current supply chain was not prepared for. This is why a lot of more recent research has been conducted on the manufacturing and distribution of these products as opposed to new product development.

5.4 Industrial PPE

Since the medical industry makes up over 40% of all PPE research in popular databases, more so in recent years. We wanted to shift our perspective to investigate engineering-related PPE research and see what topics were prevalent. Our analysis showed that some of the most popular research topics for this field were PPE to protect people from electrical arcs and bright flashes that could damage retinas. I suspect that this is due to an increase in electrical work done in the last few decades. As more and more technology become electronic, the risk of electrocution and the need for electrical PPE has subsequently increased. I expect this trend to continue over the next ten years as companies leverage renewable energy sources to develop more electric cars, appliances, and devices.

5.5 Future Work

Unsurprisingly, much of the future work related to PPE research is centered around the medical field and Coronavirus as seen by the various references and cited articles in this co-author analysis. The medical field has historically dominated the bulk of PPE research and that trend has only become more pronounced since 2020. One area of particular interest is in developing better masks to protect people from viral infections. Nowadays, it is pretty common for people to own cloth masks to cover their faces to prevent them from inhaling airborne diseases, but cloth masks can only do so much. That is why new research is underway to develop smarter, cheaper, and more effective masks.

The National Science Foundation (NSF) is funding Northwestern University to create smart masks that use batteryless electronic sensors to send data to the mask's wearer without the need for maintenance or recharging. This would remove the burden of maintaining further equipment placed on the mask wearer and would allow them to gain actual data on whether or not they have been exposed to harmful pathogens [22]. This will allow hospitals to receive real-time data from PPE to better track the rate of infection and maintain a healthy workforce.

Another project funded by the NSF is being conducted by the University of Central Florida to develop antiviral nanofilms that can actively fight and kill germs rather than just prevent them from entering the human body. The project aims to use bio-compatible particles embedded with ultraviolet light to create new antiviral coatings (https://www.nsf.gov/awardsearch/showAward?AWD_ID=2027489&HistoricalAwards=false. [15]). A development like this could yield significant results in reducing the amount of pathogens that healthcare workers are exposed to at work. The last 3 years have impressed scientists with the need for smarter and more effective masks, and with research like this, I expect to see big developments in the next few years.

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