Obesity as the Catalyst for Change: How a Societal Trend Can Impact Car Restraint Design

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

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Spring, 2021

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Introduction

Drivers of all different anthropometries, or body types, traverse an estimated 3.3 trillion miles every year in the United States, but are the cars they ride in protecting them equally (Office of Highway Policy Information, 2019)? In the past, researchers have focused their efforts on the 50^{th} percentile male in an attempt to create industry standards for testing and dummy technology (Feigenoff, 2018). Although these efforts have made cars significantly safer through the creation of seat belts and airbags, evidence suggests that factors such as body mass index can negatively affect the performance of car restraint systems like airbags and seatbelts. With obesity prevalence increasing (CDC, 2019), researchers within the injury biomechanics field are now beginning to shift their approach from setting industry standards to addressing how underrepresented demographics are impacted in car restraint design. Analyzing the development of industry standards and current research efforts will display how the rise of obesity is changing the research field. Thomas Kuhn's paradigm shift theory was utilized to evaluate the change currently occurring in injury biomechanics research. The insights gained from paradigm shift analysis showed the factors that have prevented scientific advancement from occurring sooner and the gaps that need to be filled to ensure the new and essential paradigm of protecting obese individuals can take hold. In order to understand the extent to which the injury biomechanics field has changed and the factors affecting it, the following question must be investigated: how is the rising societal norm of obesity affecting the research and development of automobile safety systems?

Methodology

To investigate the central research question stated above, document research has been conducted and analyzed using the Kuhn Cycle. The injury biomechanics field has applications that span across many areas because the human body is susceptible to injury in a wide variety of scenarios. Keywords used to narrow the number of documents being investigated include, but are not limited to "obesity," "body kinematics," "car restraint systems," "dummy technology," and "safety standards." These documents helped display the current lack of understanding injury biomechanics experts have surrounding obesity and its impact on the kinematics of the body under a motor vehicle crash. Detailed document analysis provided insight into the current research efforts and trends of the injury biomechanics field, how obesity has affected the focus of the research community over time, and an overview of the research field to describe the background and history of car restraint design. Research into other major players, such as government regulations, obesity trends in society, and car company initiatives helped investigate possible drivers behind the transition in injury biomechanics research.

Conceptual Frameworks

The main conceptual framework used to analyze the landscape of injury biomechanics research was Thomas Kuhn's Paradigm Shift Theory. Paradigm shift revealed how the prevalence of obesity in society is changing the efforts of researchers. The Kuhn Cycle is a concept used to describe how new scientific paradigms take root and can be seen in Figure 1 below. Kuhn's theory describes five different stages that occur on the way to paradigm shift: Normal Science (which creates Established Paradigms), Model Drift, Model Crisis, Model Revolution, and Paradigm Change. Normal Science is described as the regular work of scientists

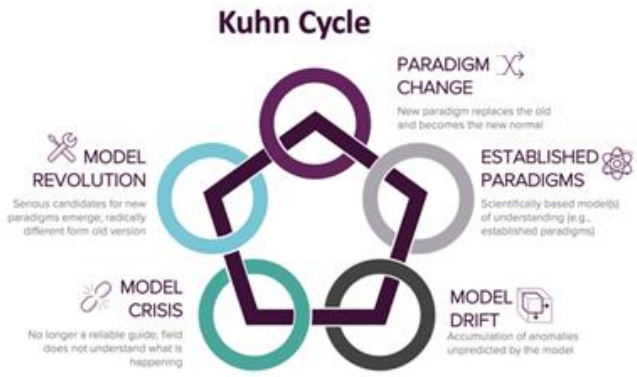

Figure 1: Visual representation of the Kuhn Cycle in its entirety.

theorizing about the laws of the world around us. During Normal Science, widely accepted models, theories, and laws turn into Established Paradigms that are rigorously tested. Model Drift occurs when anomalies, or new scientific discoveries that challenge Established Paradigms, accumulate and cause scientists to question current paradigms. Model Crisis occurs when enough anomalies accumulate and cause the scientific community to question its overall understanding of a given research field. Model Revolution takes hold when the community generates new models and theories that could more effectively solve a research problem and become the new paradigm. These new ideas are also drastically different from those that used to exist in research. In this step, the community determines which, if any, of these candidates will be accepted or rejected as a new paradigm in the field of study. This decision occurs over long periods as the community tests and slowly adopts a new paradigm. If accepted, Paradigm Change occurs and the new paradigm replaces the old and becomes the new standard of the research field (Kuhn, 2015).

Criticisms of Kuhn's theory include the following: a failure to explain additional factors that affect scientific development and an inability to be applied to every field of science (Adams, 2017). Kuhn's Paradigm Shift assumes that scientific development is only subject to influence from within its community, but many factors impact scientific discoveries (Kuhn, 2015). For

example, exterior forces, such as prejudice, ethics, etc., that suppresses certain research, can affect the path a given field takes when pushing the limits of what is known. This gap in Kuhn's theory was used to help identify these factors and how they have affected this crucial scientific advancement from occurring sooner. Kuhn's theory also cannot be effectively applied to every field due to many not being "paradigm-like." Certain research areas are built on the accumulation of scientific knowledge over time, while others work to generate and iterate on paradigms. There is evidence that the injury biomechanics field follows this "paradigm-like" nature, as specific standards and practices are prevalent in various research papers. The paradigm of current design and research standards is now coming into question as anomalies associated with gender, body mass index, and other factors are becoming more prevalent in car design. Kuhn's Paradigm Shift Theory was used to analyze the current landscape of the injury biomechanics field and how it is reacting to the aforementioned anomalies.

Literature Review and Background

Since the 1970s, researchers have proposed many different ways to model how the human body reacts to the harsh conditions of a motor vehicle crash (Viano, 1989). Crandall, et al. discusses the five surrogate types (cadavers, volunteers, anthropometric test devices (ATDs), animals, and computational models) that have been used to analyze this complex interaction. Every surrogate, while not equally effective as the next, has the same disadvantage of not being able to model the body's response with 100 percent accuracy (Crandall, et al., 2011). Despite that disadvantage, the biomechanics research field has amassed an extensive library of studies utilizing all five surrogates and achieved the ability to characterize a wide variety of motion in motor vehicle crashes (Forman, et al., 2015). Throughout years of research, biomechanics

experts have investigated almost every region of the body including the head, pelvis, abdomen, organs, and etcetera. Historically, this research effort has focused on the 50th percentile male anthropometry. With so many unknowns facing early researchers, they decided to focus on defining regulations and testing protocols for this small portion of the population. Initially, it was believed that obese people were just larger versions of the 50th percentile male, and this trend can be seen in the research conducted in the field until 2009. In 2015, Forman et al. conducted a systematic review of motor vehicle crash research in the biomechanics field from 1990-2009 and found that obesity was not investigated a single time. By focusing the research field, experts have the ability to describe how the 50th percentile male anthropometry interacts with restraint systems, such as seat belts and airbags, in detail as seen in Kent and Forman's *Restraint System Biomechanics*. While incredibly helpful in saving lives, these descriptions do not provide an explanation of how factors such as body mass index affects body kinematics, or motion, in motor vehicle crashes.

In recent years, research has transitioned from focusing on creating industry standards for testing and dummy technology to addressing underrepresented demographics, such as obese individuals (Feigenoff, 2018). While the field currently does not have a scientific explanation for why obese drivers are at a higher risk of injury, it has acknowledged that obesity is a statistically significant factor in motor vehicle crashes. In 2014, Carter, et al. found that body mass index, among other factors, correlates to a higher risk of severe injury and fatality by analyzing crash data from 2000-2010. Other researchers have confirmed this correlation by conducting math modeling and matched cadaver testing (Forman, et al., 2009; Viano, et al., 2008). Although the issue has been identified, Jason Kerrigan, the deputy director at UVA's Center for Applied Biomechanics, said that experts "still do not understand enough about the nature of obesity to

know why it makes the situation worse" (Feigenoff, 2018). Despite current research efforts, the field still has not filled the research gap that exists surrounding obesity's impact on driver safety in motor vehicle crashes.

Other factors, such as government regulations and cadaver availability, have also contributed to a lack of knowledge surrounding obesity in the research field over time. In 1966, the government passed the National Traffic and Motor Safety Act, which made the design and manufacture of automobiles a regulated industry (Bellis, 2019). Dummy technology development has lagged behind when addressing the changing demographics in the general population as a result. Currently, the National Traffic and Highway Administration (NHTSA) have the "Hybrid III" family of dummies. The adult dummies that are currently in service are the 50^{th} percentile adult male and fifth percentile adult female (NHTSA, 2021). Despite there being crash data using a 95^{th} percentile male dummy on NHTSA's website, it is not currently in use by the administration. Why would the government take away this specific dummy? This decision could be attributed to the complex approval process associated with dummy creation. Xu et al. described how the complex process has made it difficult to create new technology that more accurately describes the kinematics associated with the obese population. Getting the approval of various governmental bodies, car manufacturers, and the research community causes dummy manufacturers to be "very conservative about changing or enhancing standard devices" (Bellis, 2019). Cadaver availability is also a major issue. There are many factors, such as cause of death and history of contagious diseases that limit the number of cadavers that can be used in biomechanics research. In addition, cadavers are typically not representative of the general population. Finding cadavers that specifically fit the purpose of a given experiment is incredibly challenging and limits what research can be conducted at certain times (Singh et al., 2011).

While they are the closest thing to a living body, cadavers are a very restrictive surrogate method for research. These barriers culminate in a gap in biomechanics research and current car restraint systems are not effectively protecting the obese population.

Analysis and Discussion

Reaching Model Crisis

All anthropometries should be protected by restraint systems that currently exist in cars, but the gaps that exist in the injury biomechanics field are preventing this from becoming reality. The research field is currently in Model Crisis as defined by the Kuhn Cycle. In the past, there were many unknowns surrounding the physics behind motor vehicle crashes and car restraint systems that researchers were driven to establish paradigms for research methods, dummy technology, restraint systems, regulatory guidelines, et cetera. To narrow the number of unknowns required for paradigms to be established, researchers decided to focus on the most impacted demographic of the population at the time: the 50^{th} percentile male. This decision to narrow the research field's efforts has made an immense impact on car safety for drivers on the road. In 2019, NHTSA reported that the fatality rate per 100 million miles traveled decreased by 3.4% to produce the lowest fatality rate since 2014 (NHTSA, 2019).

Over time, researchers and government agencies have created many industry standards based on years of testing with a narrowed research focus. For example, NHTSA puts out Federal Motor Vehicle Safety Standards (FMVSS) that outline the minimum performance and safety requirements for motor vehicles on the road. These requirements range from windshield wiper functionality to complex electronic systems that control life-saving airbag deployment (NHTSA, 2011). There are other independent agencies such as the Insurance Institute for Highway Safety

(IIHS) that perform many tests with industry standard dummies and data collection devices to assess the safety of motor vehicles on the road (IIHS, 2021). The injury biomechanics research field has also established standards for optimal cadaver storage, effective experimental setups, data collection techniques, safety protocols, and much more. The Normal Science that Kuhn discusses in his book has clearly led to the creation of Established Paradigms within the injury biomechanics field just as the Kuhn Cycle suggests.

As time went on, the research field created standards, or paradigms, and the general population's average anthropometry continued to change. From 1999 to 2018, the prevalence of obesity increased from 30.5% to 42.4%, and it is still on the rise (CDC, 2019). Obesity's rise caused the research field to start analyzing if obese drivers are at a higher risk of injury with current car restraint design. The field found a statistically significant difference in injury rates of obese people when compared to a 50^{th} percentile individual. As described above, a number of studies confirmed this trend and sent the research field into Model Drift. Enough anomalies accumulated within injury biomechanics research that the current model of car restraint design could not account for. More investigation into the impact obesity has on body kinematics in a motor vehicle crash revealed that experts did not have the answers. Without answers, Model Drift soon turned into Model Crisis. In a 2018 interview, Jason Kerrigan, the deputy director at UVA's Center for Applied Biomechanics, also confirmed the onset of Model Crisis (Feigenoff, 2018).

Resolving Model Crisis: Present and Future

Model Crisis is causing the research field to shift from creating government regulations and industry standards to understanding the fundamentals of obesity's impact. Currently experts

are trying to better understand the material properties of fat as a tissue and incorporate that into existing models to develop a solution. They are also performing standard experimental setups again, such as a simple frontal crash, with obese cadavers to help identify which injuries and kinematic issues are most common under these new parameters. By getting a one-to-one comparison of data points, researchers are hoping to quickly identify problem areas and adjust current restraint design accordingly. The ultimate goal of cadaver research is to create accurate computer models that can simulate the response of an obese person in a motor vehicle crash (Feigenoff, 2018). Computer models can be run thousands of times with various restraint parameters in order to minimize injury risk. One-to-one analysis can also help inform obese dummy design because understanding specifically how humans move in a motor vehicle crash gives a benchmark for dummy performance to mimic. Currently, injury biomechanics experts are laying a solid foundation to quickly solve the challenge obesity presents in car design, but more steps need to be taken.

One major step that needs to take place moving forward is prioritizing the proper development and use of a 95^{th} percentile dummy in research. Cadavers and models are helpful tools in framing the kinematics of obese individuals, but reliable and easily repeatable real world testing equipment is invaluable to researchers. The injury biomechanics field also needs to make sure that independent and regulatory agencies, such as IIHS and NHTSA, are on the same page regarding the challenge obesity presents in car design in the future. Without the support of these agencies, new paradigms, such as dummy design and car safety requirements, associated with protecting obese drivers may not take hold. Persuading thousands of researchers across the globe of new standard testing practices and scientific knowledge will take a significant amount of time without external support. An added push from various agencies can help new paradigms to be

adopted faster and ensure they take hold across the research field. NHTSA and IIHS can also help to solidify these paradigms by putting new tests and regulations in place to push major car manufacturers to adjust designs to protect obese drivers more effectively.

Limitations

This research paper has various limitations in its analysis. The first being COVID-19 preventing meetings with industry experts to further investigate the current efforts of the research field and the external forces affecting research into obesity's impact. Document research was used to supplement the lack of interviews, but recent research papers do not provide a real-time look into injury biomechanics research. Secondly, the period for this paper was limited to 6 months. This prevented a very in-depth document library from being created to support the analysis of the research field as a whole. Thirdly, Kuhn's Paradigm Shift Theory inherently limits the scope of research that was conducted. Kuhn's theory focuses on the specific decisions of a research field over time and agencies that influence it, but fails to provide insight on how societal prejudices and biases, such as weight bias, cause a field to subconsciously prioritize or suppress certain research. Lastly, this paper only focused on the obese population. Many articles discussed in this paper found that age and gender correlate to a higher risk of injury in motor vehicle crashes. In 2020, Tondreau investigated how females are underrepresented in car restraint design, but other demographics of the population, such as older individuals and fifth percentile males, may not be protected effectively.

Conclusion

The lack of research surrounding obesity's impact has given car manufacturers and regulatory agencies the ability to ignore a significant demographic of the US population when designing car restraint systems for the public. Currently, injury biomechanics research is stuck in Model Crisis trying to understand specifically how obesity puts drivers at a higher risk of injury. Two major steps need to be taken to propel the research field out of Model Crisis. The first being the proper development and utilization of a 95th percentile dummy in research. Injury biomechanics researchers need a real-world testing method that provides reliable data and is easily repeatable. Proper dummy technology will provide a new surrogate for testing, allowing researchers to more quickly and accurately frame the basics of kinematics surrounding obese individuals in motor vehicle crashes. The second step required to break out of Model Crisis is the involvement of external actors like IIHS and NHTSA. Researchers need an external push to set standards within the injury biomechanics field. Coordinating with independent regulatory agencies will help unify the efforts of researchers across the globe and solidify new paradigms within the field. Without the help of external actors, little progress will be made and Model Revolution and Paradigm Change may never occur in the injury biomechanics field. For field experts, regulatory agencies, and obese drivers, this research indicates a necessity to look beyond safety ratings as they may misrepresent the safety for each consumer's specific demographic. Engineers have the responsibility to not take safety ratings and test results at face value and ensure every consumer perspective is being represented in the creation and testing of a given technology. Overall, this research can help push the industry to investigate obesity and develop standards, computer models, and crash dummies that more accurately represent the kinematics of an obese individual.

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