Protecting Pilots: Designing a Variable Cervical Neck Brace to Mitigate Ejection Injuries

(Technical Topic)

An Evaluation of Attitudes in Automotive Safety and Why Automobile Design is Centered Around 50th Percentile Males

(STS Topic)

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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.

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Introduction

In the United States, men and women alike rely heavily on automobiles as their primary mode of transportation, so should automobile safety standards not reflect both these populations equally? Currently, the National Highway Traffic Safety Administration (NHTSA) uses almost exclusively 50th percentile male crash test dummies in their automobile safety tests, tests which profoundly impact automobile design. The NHTSA is the bureaucratic agency responsible for devising car safety standards, and, in one of their reports, they state that "the current frontal impact protection standard assesses vehicle performance with a single size, 50th percentile, male dummy" (Stucki, 1998, p. 9). I was left wondering if women are safe in automobiles, and a thorough look at the data suggests they are not, with one report from the NHTSA stating that "the fatality risk of women drivers and RF (right front) passengers being 17.0 percent higher than it is for male drivers" (Kahane, 2013, p. 12).

My capstone group's technical work is only related to this issue in an orthogonal fashion; the goal to make airplane ejections safer for pilots revealed a need for models of multiple anthropometries that is absent in most safety designs. Current models and safety designs are centered around what is deemed a standard anthropometry, which refers to a very specific 50th percentile male. The issue of allowing generalized models to dictate safety standards is that "automotive design is directly influenced by the results of safety testing, any bias in the way cars are crash-tested translates into the way cars are manufactured." (Barry, 2019). The safety standards we test against influence design; if safety standards are such that we only test to ensure devices are safe for 50th percentile males, we end up with devices that are designed specifically to make hazardous tasks safe for 50th percentile males.

Engineers responsible for developing safety standards, injury criterion, and safety models have a bias for making all these artifacts as male, ultimately leaving female populations vulnerable. The NHTSA has focused very heavily on male drivers, but with a bit of digging it becomes clear that this is not just some overt bias; according to data from two governmental agencies compiled by Bose et al. men are nearly three times as likely to be involved in a fatal car crash than women are (Hux, 2021). However, when this raw data was further processed by data scientists and controlled for factors like miles driven and differences in vehicle choice between men and women, it was found that "The odds for a belt-restrained female driver to sustain severe injuries were 47% higher than those for a belt-restrained male driver involved in a comparable crash." (Bose, 2011). The STS research in this paper analyzes how different groups of actors deal with an interesting ethical dilemma: should engineers design safety devices for the most affected populations, or should engineers design safety devices more equitably.

Neck Saving Device to Augment Spinal Safety During Pilot Ejection

This problem of using a 50th percentile male as a model for the average population bleeds over into a variety of fields, including aircraft safety for pilots. According to the Department of Transportation, a 50th percentile male is defined as "50th -percentile adult male means a person weighing 164 pounds and possessing the following dimensions: erect sitting height: 35.7 inches; hip breadth (sitting): 14.7 inches; hip circumference (sitting): 42 inches; waist circumference (sitting): 32 inches; chest depth: 9.3 inches; and chest circumference: 37.4 inches" (Department of Transportation, 1999, 123). The technical problem that led to such a concern over lack of proper representation for large portions of the population was the development of a neck safety device, like a neck brace, for pilots who are ejecting from planes. As it stands currently many pilots of smaller stature are at increased risk of injury to the cervical spine, and there is also an

emerging problem of neck injury for all pilots of the new F-35 fighter jet, who are using the newer, and heavier, flight helmet (Salzar). One of the first indicators of this problem was when Dr. Salzar, who is my team's research advisor, showed us the work he performed on characterizing ejection bio-kinematics across multiple anthropometries. This work simulated vertical loads on manakins and then tested those values on cadavers to determine the manakin's biofidelity. The work performed by Dr. Salzar showed that flawed models hide the mistakes of flawed designs. When Dr. Salzar modeled the ejection forces on manakins everything seemed to be fine across the various anthropometries, but when he moved on to confirm those findings with cadaver tests, he found that the 5th percentile female was likely to have her thoracic spine snapped in two.

Pilots of all sizes within the United States Navy are now being outfitted with a heavier helmet than has ever been previously used, and if we allow ourselves to repeat our mistakes we will once again end up with models and safety mechanisms that do not account for smaller pilots. Using Bass's neck injury criterion as well as the Nij injury criterion which use degree of flexion as an injury indicator, my team is going to attempt to develop a computational model that will allow us to better understand the forces being applied to pilots of various size so that our brace design can better accommodate a wider variety of anthropometries, hopefully saving everyone from experiencing too much cervical spinal flexion and decreasing the incidence of injury across all populations. The neck saving device designed by my capstone team will work by running an electrical current through an electro-laminate material which stiffens only when electricity is running through it. This electro-laminate material will activate just prior to the moment of ejection in order to provide a cushion for the pilot's neck, significantly reducing the maximum amount of cervical flexion experienced by the pilot.

Current neck injury criterion models for pilots use a 50th percentile male in their models, with Bass et al. stating that their values were "scaled to a 50th percentile adult male" (Bass, 2006, p. 2). Because the intent of this neck saving device is to reduce the incidence of injury at the cervical spine across various anthropometries the first goal is to create a computational model that will provide critical values for consideration during the design process, hopefully leading to a more robust design that will work regardless of the pilot's size and gender. Currently all of the literature around neck injury criterion focuses narrowly on the 50th percentile male as being a model that works well enough, but Salzar's work shows the flaw in this and the vulnerability of populations that are not being represented; engineers have to work within the parameters they are given, so the design of this device needs to begin with a reevaluation of the current neck injury criterion to ensure the safety of everyone that will be using this device.

The Dichotomy of Design for all and Design for the highest risk

One of the keys to understanding this issue of females being nearly invisible in safety standards is uncovered by looking at how the actors across different fields define and discuss the issues of automobile safety and the populations affected. There are three separate but interconnected fields that discuss this issue. These fields can be divided into three groups of actors: engineers who were writing technical reports, academics who were publishing in academic journals, and journalists who are writing in various news media outlets. Technical reports are focused on developing safety tests with the goal of efficiently representing as much of the population as possible, academic journals are focused on analyzing data to test hypotheses and draw conclusions, and news media is generally focused on conveying a strong opinion or drawing an audience. After digesting media from all three of these fields I was left with the distinct impression that these actors belong to two groups based on their problem definition: the first favors

populations with the highest exposure while the second believes firmly in more equitable protection for all. Ultimately, how we choose to apply our resources comes down to problem definition which will always dictate what we deem the most pressing issue.

Heightened Protection for High Exposure Populations

Certain groups of actors tend to prefer using their time efficiently to cover as wide a base as possible, and so they opt for safety protocols that focus on saving populations that are deemed high exposure or high risk. Actors who write technical reports focus highly on validating and rationalizing their current models as well as laying out the general logic of their testing process as it pertains to 50th percentile males. A report written by Stucki states that "The 95th percentile group, although the least populous, experiences substantially more fatalities and MAIS 3 injuries than the 5th percentile group and has the highest injury and fatality risks…" which is a clear indicator of how these actors writing technical reports tend to think; Stucki identifies a risk to a population, but ends his assessment as quickly as he begins it by emphasizing how unpopulous this group is (Stucki, 1998, p. 11). The inclination to focus on males is likely justified in the minds of engineers by data like what that shown to the left in figure 1, which illustrates that men are more than two and a half times as likely to die in an automobile accident than women are.

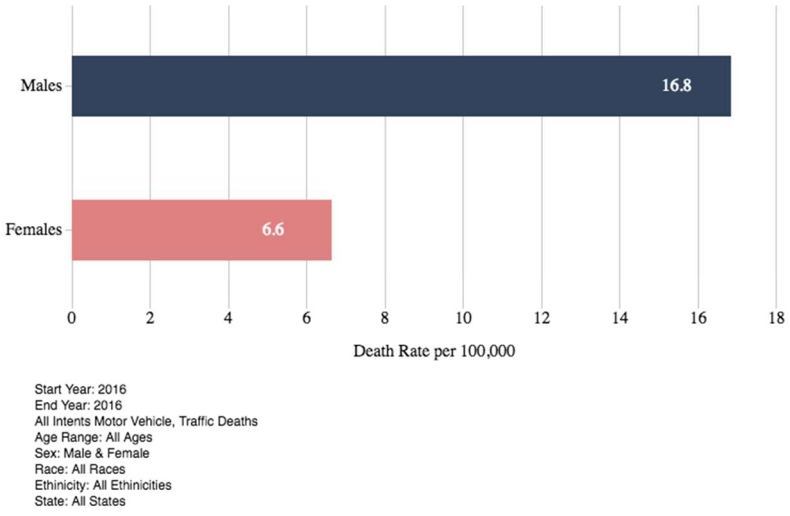

Figure 1: Graph by the American Council on Science and Health showing the death rate caused by automobile per 100,000

The report used by the NHTSA to validate current testing standards indicates clear limitations as you move farther away from the 50th percentile. According to Ferreira et al. who wrote a review on maximum abbreviated injury scale (MAIS) ratings, a 3 on the scale is defined as a "serious traffic crash injury" (Ferreira, 2016). The report by Stucki contains a table comparing injury severity and driver size, shown below in table 1; this table shows the absolute values of injuries across populations, further illustrating the fact that these outliers in the population are at significant risk compared to those who are closer in stature to the 50th percentile male. This table shows this increased exposure when you stop to look at the ratios and consider a standard distribution; in a standard distribution one should expect 68% of all injuries and fatalities to fall within one standard deviation of the average, but this curve is significantly flattened, and even inverted in the case of the MAIS 2 injuries. One of the major conclusions drawn from the Stucki report is that both smaller *and* larger individuals are at much higher risk of injury, but this fact is again accompanied with a statement about "decreased crash exposure" (Stucki, 1998, p. 2).

According to another NHTSA report by Kahane women are far more vulnerable than men in car crashes with similar circumstances. In Kahane's report, which is a data analysis on the effects of age and gender on population vulnerability, he writes that women are far more likely to sustain injuries to the neck, abdomen, and legs (Kahane, 2013, p. 9). Despite reporting on a lot of facts Kahane never attempts to diagnose the issue, opting to simply state the facts and the largest potential influences that may give rise to the disparity between men and women in automobile vulnerability. The language in both these reports shows a clear bias for efficiency and populations with higher risk exposure; our current safety standards reflect this bias, using

almost exclusively male crash test dummies and working on the assumption that these models scale accurately for females.

Estimated Annual Driver Injury/Fatalities in Left Offset Impacts With Air Bags

		DRIVER SIZE GROUP		
INJURY LEVEL	**Total**	**5th Percent**	**50th Percent**	**95th Percent**
MAIS 2	45,924	11,796	19,819	14,309
MAIS 3	11,520	1,261	7,307	2,953
Fatalities	4,243	224	3,004	1,015

Table 1: NHTSA's report on estimated driver injury/fatalities in left offset impacts with air bags, showing both injury severity as well as number of fatalities per population. (Stucki, 1998, p. 11)

Equitable Protection for All

Actors who publish in academic journals and write for news media outlets fall distinctly into the camp of believing that safety standards and safety design should be focused on protecting the entire population equitably. In the paper by Bose the question of crash vulnerability across genders is again the question of interest but the problem is dealt with much more directly. After running the analysis Bose found that females are 47% more likely to sustain severe injuries than males under similar crash conditions, and from this result they drew a very strong conclusion: "health policies and vehicle regulations must focus on effective safety designs specifically tailored toward the female population for equity in injury reduction" (Bose, 2011). The authors of these academic journals show a clear desire for more equitable outcomes and do not shy away from explicitly stating this in their papers. This schism where one group of actors is focused on high-risk populations while the others are focused on equitably across populations likely arises from the differences in problem definition between engineers and academics; engineers see their ability to focus narrowly on the technical aspect of the issue as a virtue,

whereas actors in the academic realm feel much more comfortable trying to place their work and the conclusions drawn from it into the broader sociotechnical context.

Another group of actors that stands in direct opposition to engineers is journalists. There is no shortage of news articles covering this topic, all of which seek to fully leverage statistics and testimonials in favor of the conclusion that this lack of equitable protection is a problem that needs to be addressed. Kuhn, an author for Fast Company, writes that the NHTSA is contributing to social inequality and that this problem is "swiftly solvable" (Kuhn, 2021). A writer for The Guardian wrote with similar conviction that the oversight of the NHTSA, stating that "The gender data gap is both a cause and a consequence of the type of unthinking that conceives of humanity as almost exclusively male" (Criado-Perez, 2019). Sarah Holder, a Bloomberg author, writes at much further length on the issue and strikes a much better balance in her definition of the problem, calling on a variety of specialists in order to best encompass the scope of the problem. Sarah goes on further to discuss that while it is obvious that there are differences between males and females in their anatomy, it is not obvious which of these differences are the culprit in causing the increased risk to females in automobile accidents. Problem definition is ultimately what divides the equitability group from the high-risk exposure focused group, but those who are betting on equitable protection have one distinct advantage over those focused narrowly on high-risk populations; we have no way of knowing how advances in technology will affect which populations are at the highest risk. As women continue to increase their driving exposure and self-driving cars limit the impact of crash exposure caused by unsafe habits, how long will it be before women are the higher risk population?

Conclusion

My capstone group's technical work is only related to this issue in an orthogonal fashion; the goal to make military jet ejections safer for pilots revealed a need for models of multiple anthropometries that is absent in most safety designs. Current models and safety design are centered around what is deemed a standard anthropometry, which almost always refers to a 50th percentile male. The issue of allowing generalized models to dictate safety standards is that "automotive design is directly influenced by the results of safety testing, any bias in the way cars are crash-tested translates into the way cars are manufactured." (Barry, 2019). To combat this problem my capstone team intends to develop and validate a set of neck injury criterion that better scales across anthropometries, and that better translates to females. Women are far more vulnerable than men both sitting in a cockpit and behind the wheel, but by developing better models that allow us to design around female needs, the disparity between men and women can be lessened.

Word Count: 2601

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